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Proceedings—Workshop on Engineering and Hydrology Research Needs for Phosphate Mined Lands of Idaho

Pocatello, Idaho, June 5-6, 1984

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EXECUTIVE SUMMARY

The western phosphate field, of which southeastern Idaho is a major part, currently supplies about 14 percent of the United States production of phosphate. Projections for the next 20 years are that demands will continue with possibilities of substantial growth with improved economic situations. Researchers, land managers, and mining industry officials have established strong cooperative ties and are optimistic about the future. Effective reclamation programs can improve both mining and reclamation operations.

This report is a result of a June 1984 workshop on engineering and hydrology research needs for phosphate mined lands of Idaho. Specialists from many agencies, universities, and companies reviewed the rehabilitation progress and explained ongoing research projects. The abstracts of these sessions are included in this report. The workshop participants then divided into four working groups to identify "knowledge gaps" that need the attention of future research. These groups were (1) coordination of mineral development with surface resource management, (2) mine plans, (3) risk analysis, and (4) mined land stabilization and costs.

SYMPOSIUM SUMMARY

ENGINEERING AND HYDROLOGY PRACTICES IN THE SOUTHEASTERN IDAHO PHOSPHATE FIELD

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INTRODUCTION

This paper attempts to summarize the present state of the art of hydrology and engineering practices in the southeastern Idaho phosphate field. The information presented is of necessity broadly stated and serves as background material for the research needs that follow this paper. Present engineering and hydrology practices generally followed by the industry are quite sophisticated, as shown by the demonstrated success of land reclamation and revegetation on mined lands. Such success cannot be achieved without good control of drainage and embankment design and construction. However, because of the size and scope of the phosphate mining operations, concerns with the operating costs and the stability and hydrology of affected lands persist both within the industry and by the land managers. This paper gives the reader an appreciation for the practices and the problems of engineering and hydrology, and provides a basis for increased understanding of the concerns of both land managers and the industry.

Climate

The climate in southeastern Idaho is strongly influenced by the north- and south-trending mountain ranges and valleys. These mountain ranges are almost perpendicular to the prevailing west and northwest winds. Variability of climate between valley and mountain locations is pronounced. Mean annual precipitation ranges from about 25 cm in some of the drier valley bottoms to about 127 cm in some mountain locations. Precipitation tends to increase with increasing elevation, but the relationship is variable depending upon the aspect, height of the ridgetops, slope steepness, and direction of the prevailing wind. Increased precipitation at the higher elevations is more pronounced in winter than in summer. Usually less than half of the annual precipitation falls during the warm season, May through October. During most of the cold season, November through April, precipitation falls as snow, the proportion of snow to rain increasing with elevation.

The growing season (nonfreezing period) averages 142 days at Pocatello, one of the warmest points in the western phosphate field. At many mountain locations the growing season is less than 60 days. Temperatures of less than 0 ^{0}C have been recorded during every month of the year at Conda, ID, and Afton, WY, both valley locations. Frost hazard persists all summer at all elevations over 2 100 m. Maximum summer temperatures are generally warm at all elevations, but large (19 ^{0}C) diurnal temperature ranges, caused by cloudless days and radiation cooling at night, are common. Minimum winter temperatures are influenced by arctic air masses moving down the western side of the Rocky Mountains. These air masses may bring several consecutive days of subzero temperatures. At Afton (1 864 m elevation) the record cold temperature is -48 ^{0}C.

Soils

For the most part, soils in the area have not been mapped in detail. There are at least 16 great soil groups in the area. These range from deseritic aridisols to the cold subhumid alfisols. The principal soils are the subhumid mollisols and the gray-wooded alfisols. On these soils, organic matter accumulates rapidly and the

soil surface horizons are thick and dark. On the steeper slopes the soils are the entisols and inceptisols. Most of the soils are residual and have developed from sedimentary parent materials--limestone, cherts, and sandstone. Soil pH is nearly neutral, ranging from slightly basic to slightly acid. Because surface mining for phosphate violently disrupts the surface soils, the properties of the underlying subsoils and parent materials become unusually important. Unfortunately, information on subsoils is even more sketchy than information on surface soils. However, it is important to note that subsoil phytotoxicity is rare to nonexistent.

Geology and Physiography

The operating mines in southeastern Idaho exploit outcrops of the Meade Peak Phosphatic Shale member of the phosphoria formation. These outcrops often occur along or near ridgetops and are the surface exposure of former blanket-type sediments that were deposited in a Permian sea 225 to 280 million years ago. They were subsequently covered by younger sediments and lithified. Later uplift, folding, faulting, and erosion of the younger rocks created the present outcrop pattern.

Sources of information about the regional geology are Mansfield (1927), Armstrong and Cressman (1963), Cressman (1964), Armstrong and Oriel (1965), and Mabey and Oriel (1970).

The area has many geologic faults that are young and potentially active. Movement of any one of them would not be surprising. Such movement would cause earthquakes that would be felt most strongly near the fault. Breakage of the land surface would also be possible. On the basis of historical earthquakes and the assumed locations of future earthquakes, there is less than a 10 percent probability that a quake of magnitude VIII, or greater will occur near Soda Springs during the next 50 years (Bones 1978). An earthquake of magnitude VIII did occur in the Pocatello Valley on March 27, 1975. Malad City, 23 km northeast of the epicenter, sustained $100,000 in damages.

Southeastern Idaho is characterized by north- and northwest-trending mountain ranges and valleys that form part of the middle Rocky Mountains physiographic province. The entire area is over 1 350 m high, the highest point being Meade Peak, about 11 km east of Georgetown. The peak rises to 3 035 m. The relief between Meade Peak and Bear Lake Valley is about 1 200 m. Local relief of 300 to 600 m is common. Folding of the rock layers early in the geologic history of the area, and subsequent block faulting parallel to the fold faces, produced the linear trend of sharply defined valleys and ranges, features similar to those in the Basin and Range physiographic province to the southwest of the area.

MINING METHODS

In southeastern Idaho the sedimentary beds have been severely faulted and folded by crustal deformation. Local sections may dip at any angle from nearly horizontal to vertical. Erosion has occasionally exposed the phosphate-bearing formations in narrow bands along the flanks of the simpler folds or in the irregular fringes of the more complexly folded and faulted areas. To mine the phosphate ore, the mine operators use either shovels and trucks or scrapers and bulldozers. The main bed ores, suitable for use in wet-process phosphoric acid plants, and furnace shale, used in electric furnaces for the recovery of elemental phosphorus, are selectively mined. Excessive amounts of calcium oxide, iron oxide, magnesium oxide, silica, and organic matter are detrimental to the refining process. Recognizing the need for uniform and uncontaminated plant feed, mine operators have developed the ability to selectively mine and blend large tonnages of varying grade phosphate rock.

Mining methods used in the western phosphate field are generally similar. Before a pit is opened the area is cleared. Merchantable timber is harvested while the rest of the vegetation is burned or pushed aside. Topsoil is usually not salvaged or stockpiled for later reuse. The topsoil is often thin, sometimes less than 15 cm. Frequently there is an abundance of middle waste shales within the mine profile that are not phytotoxic and provide an adequate, if sterile, rooting medium for revegetation. The texture of these middle waste shales is a gravelly silt loam or a gravelly sandy loam.

Pit excavation requires drilling and blasting. Overburden wastes are removed with large electric shovels and trucks or with self-propelled or dozer assisted scrapers. Large front-end loaders may also be used. Depending upon the need of the operator it is not unusual for a pit to be mined, temporarily closed, and then reopened at a later date.

Pit depth is determined by the continuity of mineralization, the degree of ore alteration by weathering, and the stripping ratio. The stripping ratio is a measure of how many units of waste overburden rock are removed for each unit of ore mined. From the unit cost of stripping and ore removal and the unit value of the ore, the economic mining depth can be calculated. Stripping ratios of 3:1 to 5:1 are common during the various stages of mining. In addition to economic factors, the eventual pit depth is governed by the stability of the pit walls and the groundwater conditions around the walls and in the pit.

The mineralized zones are selectively mined and transported to blending piles at the mine tipple or loadout facility and then further transported

to the processing plant. Winter weather conditions dictate that the ore be mined, transported, and stockpiled at the processing plant during the warm season. Winter handling of the phosphate rock in trucks or railroad cars is often unsatisfactory due to the ore freezing in the car.

Waste materials generated during the mining generally consist of shales, limestones, and chert. The chert rock varies but can be broken into two groups, hard chert and soft chert. The soft cherts could be classified as organic siltstone.

Three methods are used to dispose of waste overburden: (1) they are backfilled into an existing pit; (2) scraper built dumps are constructed in lifts from the bottom to the top; or (3) waste dumps are constructed by trucks end dumping over angle of repose embankments. Such embankments are then graded by bulldozers downward to the desired steepness and shape. Such waste embankments are constructed from the top downward. There is considerable gravity sorting of the rock material when a dump is constructed in this manner. Larger materials roll to the bottom while finer materials remain nearer the top. Gravity sorting is believed to promote mass stability within such dumps because of better drainage provided by the sorting. However, this construction method also results in low placement densities because most of the material receives little compaction effort. Scraper-built dumps constructed from the bottom to the top result in greater placement density, but this method is used less frequently than the other methods. This method is used primarily where a low, contoured dump is to be built, usually less than 750 thousand cubic meters.

Shaping and grading the slopes of waste embankments is done (1) to promote increased surface soil stability, (2) to permit revegetation of the embankment with farm-type equipment, and (3) to increase the visual qualities of the embankment by blending the shapes more neatly into the surrounding terrain.

LAND RECLAMATION

Land reclamation--the process of returning land disturbed by mining activities to productive uses--is strongly affected by engineering and hydrologic considerations. Reclamation planning starts early in the development of the mining concepts. Mining methods, haul routes, waste volumes, waste embankment locations and size, and so forth, all affect how and when the final reclamation is done.

Satisfactory land reclamation provides for land stability and the establishment of vegetal cover to build the soil, protect the soil surface, and restore vegetative production.

Revegetation

The Idaho phosphate industry has a good record of successfully revegetating waste embankments and other disturbed lands. Because of the low population density and the rural or wild nature of the phosphate mining areas in southeastern Idaho, reclaimed lands will normally be used for forage or browse production for sheep, cattle, and big game animals. On some sites timber production may be a long-term use. The land and streams are valued for their water yield and fishery resource. More intensive uses are not expected in the forseeable future.

The degree of success of a revegetation effort is strongly affected by preparation of the site. Site preparation includes shaping and grading to a desired slope steepness, ripping, topsoiling, and making the seedbed. Slopes steeper than about 3:1 are normally not safe for revegetation equipment because of the rollover hazard. It is often necessary to rip the surface materials of waste embankments to allow water, air, and root penetration into the waste. Ripping depth and spacing vary with the operators and the available equipment. Ripping to a depth of about 30 cm can be done with a large spring-tooth harrow set to run deep. Ripping more deeply than 30 cm requires rigid steel ripping tines. Topsoiling is an effective and desirable treatment for revegetation success. Topsoil, as used here, includes a variety of natural topsoils, shallow subsoils, and any of the soillike middle waste shales. Topsoil depths vary from about 0.3 to 1 m depending upon the site conditions and the availability of soil materials. Seedbed preparation usually consists of harrowing once or twice after the ripping operation. Both springtooth and vibrating shank harrows have given good results. Seeding and then firming the seed into the seedbed can be done with either a seeder-packer or a seed drill.

Fertilizer is required to promote rapid growth of newly seeded stands of grasses and forbs. Heavy grass stands are desirable both for soil protection from erosion and for additions of below ground organic matter to the waste. Fertilizer rates should be based on a fertility analysis of the waste material. Where shrubs are being seeded with grasses and forbs, the rate of fertilizer application should be reduced.

A large portion of the reclamation research in the western phosphate field concerns identifying plant species that are adapted to mining disturbances. Both native and introduced species have been used with success. Lists of adapted plant species have been published by Richardson (1981) and Farmer (1979). Seeding rates for fall plantings of grass and forbs on fertilized sites run from 28 to 45 kg of seed per hectare. Fall is the preferred planting season.

Soil Erosion

In most years the melting snowpack causes most of the soil erosional losses. However, the occasional high intensity summer thunderstorm can create deep rills and gullies in bare waste embankments. Some of these damaging storms may have fairly short return periods of, say, 2 to 5 years. The main difference in the erosion amounts created by snowmelt as opposed to a rainstorm is associated with the raindrop impact of the storm. Raindrops are an effective agent for detaching soil particles from the soil surface. Melting snow lacks this drop action. In addition to differences in soil erosion due to rainstorms versus snowmelt, there are large differences in erosion between bare and revegetated waste embankments. There are also significant differences in soil erosion due especially to slope steepness and secondarily to slope length and aspect.

Well-revegetated waste embankments with a slope steepness of about 3:1 exhibit low rates of soil erosion. Measurements conducted by the Intermountain Station have placed these amounts variously at between 250 and 1 100 kg/ha per year for moderate rainstorm or snowmelt events. These amounts are lower than would be expected on many farming operations. On the other hand, soil erosion rates on bare waste embankments with slope steepness varying from 4:1 to 2:1 can be dramatic. Measurements of erosion amounts range from 9 to 1 744 mt/ha per year. The average rate was 190 mt/ha per year. Fortunately, these rates of erosion are controllable by making provisions for the safe disposition of surface runoff waters and by prompt and serious revegetation efforts.

Mass Stability

Reclamation programs need to consider the long-term mass stability of overburden waste embankments. Some desirable characteristics of waste embankments are:

1. They should be engineered structures that provide for long-term stability with low maintenance.

2. They should not interfere directly or indirectly with the use of downstream resources.

3. They should provide for a level of land productivity comparable with, but not necessarily the same as, premining conditions.

To achieve these reclamation goals for waste embankments it is necessary to consider a variety of engineering and hydrologic concerns associated with the waste materials themselves as well as the physiography of the site receiving the waste and the nature of hydrologic and meteorologic events of interest.

WASTE EMBANKMENTS

Waste embankments are a significant feature of phosphate mining in southeastern Idaho. They range in size from a few thousands of cubic meters to more than 30 million cubic meters. Even larger embankments will probably be constructed in the future. Nearly all of the embankments can be classified into one of three configurations based on their relation to the natural topography: sidehill, head-of-valley fill, and cross-valley fill (fig. 1).

Evaluating Embankment Sites

This section presents some of the important mass stability considerations that are conditioned by the selection of the waste site. There are other considerations that operating companies use in site selection in addition to those associated with mass stability. Usually these additional considerations involve the capacity of the site to hold waste and the cost of hauling overburden to the site. Also important are the potential costs of mitigating environmental impacts arising from the waste embankment and the costs of reclaiming the embankment. However, we will consider only the following:

1. Natural site hazards
2. Shape and nature of the site
3. Geology and stratigraphy
4. Windward terrain, fetch, and topography
5. Aspect

Natural site hazards.--In the Idaho phosphate field the common natural hazards at a site are over-steep slopes, a propensity toward natural slides, shallow transient groundwater tables, and weak foundation rock.

Natural slope steepness is a key factor related to the occurrence of waste embankment movement or failure. Slides can only occur when natural slopes are steep enough for some combination of factors to produce a stress great enough to overcome the natural slope resistance to movement. Slope steepness is a key factor in selecting a location for a sidehill waste embankment. In any spoil mass with an upper surface that is not horizontal, shearing stresses develop internally that tend to move the upper surface downward. If the internal shear stress exceeds the shear resistance, movement will occur.

Landslides associated with mining activities have been noted in several cases. Some cases have been pit failures, probably due to unloading the foot wall. Other cases have been slope failures, probably associated with slope loading on inherently weak soils or with loading at too high a rate.

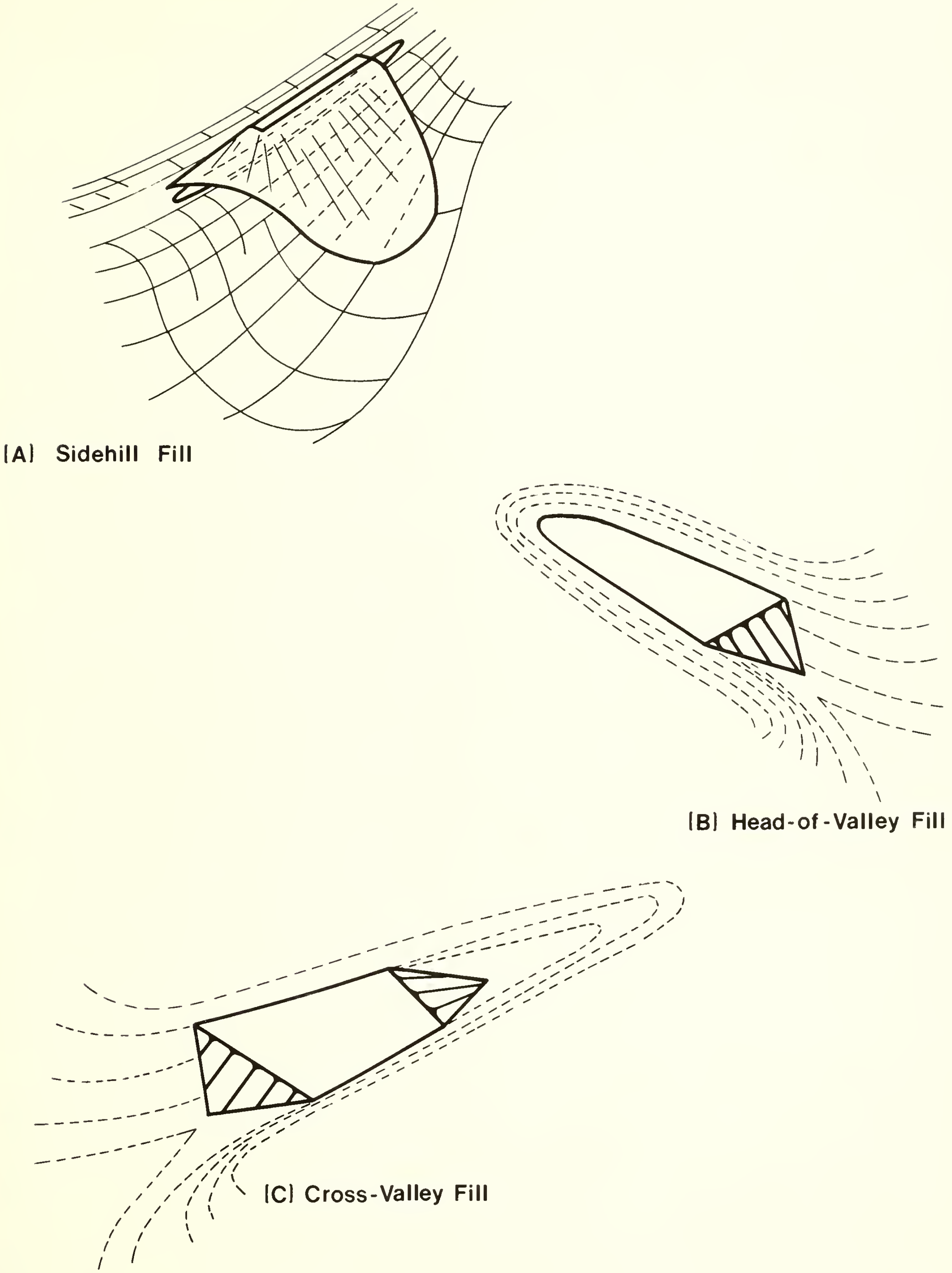

Figure 1.--Three commonly used configurations for overburden waste embankments.

Transient groundwater tables are common on valley sidehills during peak snowmelt. This is not necessarily a problem. However, groundwater can move from the sidehills into the waste embankments increasing the water saturation and pore pressures within the embankment. The known failures resulting from this mechanism have been small, less than 4000 cubic meters.

Failure in the foundation of waste embankments is not common. We only know of one instance. However, with the increasing size of waste embankments being built today, foundation investigations assume increasing importance.

Shape and nature of the site.--Because cross-valley fills are relatively new in the Idaho phosphate field, there is not a lot of accumulated experience with them. Also, the cross-valley fills tend to be larger than either sidehill or head-of-valley fills. However, assuming no foundation failure and that failures originate within the waste material itself, then those embankments that must transmit the least water have the most potential stability. From most stable to least stable these would be: sidehill, head-of-valley, and cross-valley. This ranking appears justified by observational data, but the number of cases is too small to make a sound judgment.

The shape of the receiving site needs to be evaluated. If we consider the plane slope a benchmark against which to measure other slope shapes, convex slopes are less stable and concave slopes are more stable. In unstable areas with a history of landslides, a frequent site for starting such slides is just below a convex break in slope in the head of a small drainage.

Geology and stratigraphy.--Slopes that are nearly parallel to bedding planes of sedimentary parent materials, or parallel to the direction of jointing and fracturing of any parent material, are susceptible to landslides.

In the parallel situation, stratigraphy promotes sliding in two ways. First, the surface of the parent materials and interfaces between strata within the parent materials provide zones of weakness and ready-made failure surfaces. Second, parallel bedding with the surface tends to concentrate and return percolating water back to the surface. Water coming to the surface may produce excess pore-water pressures, lubricated slip surfaces, or both.

In the situation where the stratigraphy is more or less normal to the surface, the stratigraphy contributes little to possible failures or landslides. This is because weakness in the bedding plane is normal to the direction of failure. Such slopes are also more stable because the strata tend to direct water down the bedding planes away from the surface.

Windward terrain, fetch, and topography.--In the upwind direction, the shape of the ground surface, intervening topographic barriers, and snow fetch distance all influence the amount of snow accumulation and the occurrence of snowdrifts. As a general rule in the Idaho phosphate field, minimizing the amount of subsurface water within a waste embankment is desirable, meaning we should try to limit the amount of snow accumulation on the waste embankment surfaces.

Aspect.--In general, south aspects do not have as much difficulty with embankment stability as do north or east aspects. This difference in stability is associated with the influence of aspect on snowmelt rates. On south aspects snowmelt typically starts in February. Melt rates are slow because of the cold night temperatures. The snowpack is often completely gone by the second week of April. On north aspects snowmelt usually starts in March and peak melt rates usually occur in late May or early June. This difference in melt rates can be accentuated by a long, cold spring season that delays snowmelt until the onset of hot weather. Not only are peak melt rates higher on north aspects than on south aspects but north aspects generally accumulate more snow. These factors generally mean that north-sloping embankments must transmit more water than south-facing embankments.

Design and Construction

A brief description of the methods and techniques of constructing waste embankments has already been given under "Mining Methods." Here we want to look more closely at the general information requirements and the techniques used to design embankments. At least in the larger embankments, a usual first step is to develop stability analyses.

After a site has been chosen to hold the overburden waste material and the necessary site investigations have been conducted, stability analyses are performed. The analysis results in a factor of safety against sliding, which is the ratio of forces resisting failure to the forces that tend to cause the completed structure to fail. Stability analyses use soil, spoil, and rock strength values obtained from laboratory tests. The anticipated soil water or groundwater conditions within the embankment are also considered. These strength values and conditions of the soil water content, along with the various geometric configurations proposed for the embankment, are used in the factor of safety analysis. In a typical analysis the proposed configuration of the embankment including the outslope of the embankment is varied until an appropriate factor of safety is achieved. Usually the degree of water saturation is also considered as a variable to see what effect saturation has upon stability.

The most likely shapes and positions of the slip surfaces are determined by the engineer, based largely on observations made during the site investigation and on skill and engineering

judgment. Various geometries of potential slide masses are investigated until the geometry that provides the lowest acceptable factor of safety is determined. A sloping mass on the verge of failure has a factor of safety of 1.0. If an analysis indicates a factor of safety of less than 1.0, a slide would be highly likely. Calculations of geometric configurations giving factors of safety greater than 1.0 provide the basis for an acceptably safe embankment.

Minimum acceptable factors of safety probably should be determined on a case-by-case basis. Some guides may be useful. For earth-fill dams in a steady state seepage condition--a full reservoir--a factor of 1.5 is generally acceptable. It seems reasonable to assume that this would be the upper limit in the factor of safety for a waste embankment. A lower factor of safety than that required for long-term stability is also tolerable during the construction period. On most sites factors of safety of about 1.15 for construction and about 1.3 for long-term needs seem reasonable.

In summary, the steps leading to an evaluation of the factor of safety of an overburden waste embankment are (National Research Council 1981):

1. A feasible failure surface is selected, according to the layering and strength of materials in the slope. An experienced analyst can predict the most likely places for a slip surface by examining slope cross-sections that show the distribution of soil/rock properties and the distribution of pore-water pressures.

2. Forces and moments acting on each element of the slope are calculated according to the analysis method of choice. We will not discuss methods here. In any case, equations of force and moment equilibrium are solved for the combination of geometry, material strength, and pore-water pressures selected.

3. The factor of safety is computed by comparing the shearing resistance necessary for equilibrium to the available shear strength along the selected failure surfaces.

4. Steps 1 through 3 are repeated successively with different failure surfaces until the critical surface--the one with the lowest factor of safety--is located.

Of course, all of the factor-of-safety information assumes that adequate drainage of free water on or within the embankment is provided. In the case of a cross-valley fill, the additional complication exists of transmitting a live stream through the base of the embankment.

Information Needs

Information needed for planning and managing waste embankments in the Idaho phosphate field is suggested in table 1. Three categories are used for each item. While the elements listed in table 1 are suggestive of the data needs, the list may not be all-inclusive and the categorical needs are only approximate.

Table 1.--Information needed for planning and managing embankments

Element	Soils	Bedrock	Spoil
Stratigraphy	x	x	s
Geologic structure	-	x	-
Lithology including spoil	-	x	x
Aquifers	-	x	s
Springs	-	x	s
Unit thickness	x	x	x
Texture	x	s	s
Grain size	x	s	s
Weathered thickness	-	x	-
Weathering potential	-	s	x
Mineralogy	-	s	-
Clay mineralogy	s	-	o
Slaking character	-	s	s
Soil dispersion	-	-	s
Density	o	-	s
Rock soundness	-	s	x
Rock quality	-	s	x
Rock broken size distribution	-	s	x
Unconsolidated strength	o	-	s
Atterberg limits	o	-	-
Water content	-	o	s
Pore water pressure	-	-	s
Water/density relation	s	-	s
Permeability	o	o	s
Shrink/swell	o	-	o
Soil classification	o	-	-
Soil-rock analysis			
P,K	o	-	x
Other elements	o	-	s
pH	o	-	o
Salinity	-	-	o
CEC	s	o	s
Total carbonates	-	o	o
Organic content	s	-	o
Groundwater			
pH	-	-	o
TDS	-	o	s
Suspended solids	-	-	s
Hardness	-	-	o
Temperature	-	-	o
Chemicals	-	-	o

Key: x Data considered to be necessary at most sites
s Data that might be selectively necessary
o Data that might be occasionally necessary
- Data not generally needed.

HYDROLOGY AND DRAINAGE OF EMBANKMENTS

The hydrology of the forest and range lands of southeastern Idaho has not been intensively studied. Hydrology studies and acquisition of hydrologic data on mined lands have, for the most part, been started only since 1977. Although the number and scope of hydrology studies in the Idaho phosphate field have been limited, our knowledge of the hydrologic response to mining disturbances is expanding at a good pace.

Southeastern Idaho has a poor hydrologic data base. With a single exception all of the phosphate mines are north and east of Soda Springs. The closest weather station is at Conda. The long-term annual precipitation at this station is 48 cm. However, this value may or may not be representative of the precipitation at the mine areas. Generally the mines lie at higher elevation and receive substantially greater snowfall than either Soda Springs or Conda. Precipitation records have been kept since 1980 by the Intermountain Station (Farmer) at the Dry Valley Mine at an elevation of approximately 2250 m. For the water years (October 1 to September 30) 1981, 1982, 1983, and 1984 the recorded amounts were 44, 83, 80, and 84 cm, respectively. Reliable records of streamflow in the mining area are limited to the Blackfoot River. Records in smaller tributary watersheds are almost totally absent except for a station on Maybe Creek operated by the Intermountain Station.

Infiltration

The rates of water infiltration into waste embankments has been a source of interest and misinformation for some time. Only a few years ago, embankments were sometimes described as impermeable with leaks. We now can state with confidence that embankments are not impermeable (Knopp and Farmer 1980; Kotansky 1984). Because infiltration is a surface phenomenon, it is not surprising that infiltration shows a large variation with surface materials. Several types of middle waste shales that were used as surface dressings on waste embankments have been studied. Infiltration varied from 2.4 to 4.4 cm/h, a surprisingly narrow range of values. Several "chert" materials have also been studied. These materials would probably be better classified as hard or soft siltstones, but "chert" has become common usage in the industry and will be used here. Finely fractured chert, about 5 cm minus, has high infiltration rates with uncompacted areas running in excess of 20 cm/h. Compacted chert, as in roadways, is not much less, perhaps 19 cm/h. As a comparison, some relatively undisturbed forests in the area will run about 24 cm/h. These are typical infiltration rates.

The complement of infiltration is surface water runoff. While the middle waste shales are used for surface-dressing for revegetation, their relatively low infiltration rates will produce more runoff and soil erosion. We would also speculate that the infiltration rates on middle waste shales will increase with the time since establishment of good vegetal cover. High infiltration rates on the chert are not without drawbacks. High infiltration rates mean that more water is transmitted into the interior of the waste embankments, with possible adverse influences on pore-water pressures and mass stability.

Groundwater

There is little doubt that overburden waste embankments accumulate large volumes of water. During snowmelt the surface 6 m of waste material approaches a fully saturated condition. Phreatic surfaces--free water surfaces--have also been observed within embankments. However, these facts do not necessarily indicate a groundwater condition in the usual sense. For instance, the transmissivity of the material and the volumes of water are such that little or no water could be pumped from the waste materials. The influence of this water within the waste materials upon positive pore-water pressure is probably slight under most conditions. Since 1980 in several arrays of multiple piezometers to depths as great as 45 m, I (Farmer) have been unable to measure any significant pore-water pressures.

Snowmelt does add considerable water to waste embankments. However, this is a transient condition. Normally, embankments will contain a maximum amount of water in late May or early June. This water will drain down into the waste materials and probably out into the fractured bedrock until the following recharge or snowmelt. Late February or early March is normally when embankments hold the least amount of internal water.

However, internal soil water in waste embankments is not entirely innocuous. Many small shallow mass soil flows have been initiated by saturated surface soils on waste embankments. Typically, these soil flows are small, under 4000 cubic meters. They most frequently occur on slopes steeper than 3:1, and the depth of failure of about 1 meter. The potential for more destructive flows of this type has not been evaluated.

Water Budgets

One of the authors (Farmer) has collected some water budget data but has not yet published them. The highlights of that data are presented here.

This work was done on a small scraper-built embankment of about a 195 thousand cubic meters. The embankment was entirely surfaced with middle waste shales and vegetated to a heavy stand of grass and forbs. The embankment is in the bottom of an ampitheater-like bowl and has a watershed of 15 ha above it.

Precipitation on the area during the 1978 water year was 72.4 cm. This amount was augmented by an additional 55.3 cm of water that moved through the embankment as lateral subsurface inflow from above, and an additional 15.3 cm of water transported onto the embankment as blowing snow. The total water that was transmitted by the embankment was the sum of these three components, or 143 cm.

This water was disposed of in several ways. The most important were evapotranspiration (68.3 cm), surface runoff (33.0 cm), and deep seepage (38.4 cm). The rest of the water was involved as slight changes in soil water storage.

While these data may not be representative of all waste embankments, they are probably representative of scraper embankments. Their major importance is probably as an insight into the hydrologic functioning of such embankments. They are useful in thinking about revegetation plans and sediment trapping measures and devices.

Water Quality

Water quality has, to date, never been a serious concern. However, the available documentation will be examined briefly. Water quality was determined in 1983 for the water emerging from a large embankment and for a small permanent stream downstream from an active mining operation (table 2).

Table 2.--Water quality analysis conducted on mining affected samples collected November 1983, mg/liter

Element	Embankment	Stream
Alkalinity	157	141
Aluminum	<0.1	<0.1
Beryllium	<0.005	<0.005
Boron	<0.02	0.022
Calcium	117	88
Total carbon	1.7	3.2
Chromium	<0.025	<0.025
Electrical cond.	831	633
Iron	<0.02	0.053
Magnesium	25	18
Manganese	0.009	0.021
Nitrate	3.9	2.0
Nitrite	0.002	0.008
Dissolved oxygen	8.2	7.5
pH	8.3	8.6
Orthophosphate	0.0316	0.0432
Total phosphorus	0.0639	0.0648
Potassium	1	1
Silica	7	7
Sodium	5	4
TDS	489	353
Suspended solids	5	29
Total solids	509	383
Temperature, celsius	3.0	4.5
Zinc	<0.005	<0.005

Note: Electrical conductivity units--micromhos/cm pH in standard units.

These water samples show very acceptable quality; they are very near the quality of potable water. Platts and Martin (1978), studying water quality in the mining area with respect to the fishery, concluded that mining had not degraded the waters in the area for either fish or benthic stream organisms.

Drainage

This section discusses three types of drainage: (1) drainage of surface water runoff, (2) drainage of water within waste embankments, and (3) drainage of live streams through french drains in the case of cross-valley fills.

Controlled drainage of surface water runoff on the mining areas, including waste embankments, is important. Today drainage controls are well understood and the occasional mistakes that arise can usually be attributed to the new or careless equipment operator. Today's understanding has developed from the mistakes of the past. Two difficult lessons come to mind. First, it is invariably a mistake to concentrate water on waste embankments in ponds or in contour trenches. Several failures and near failures of waste embankments have resulted from violating this rule. Second, ditches on-grade that are used to provide drainage will usually freeze and ice over. The operation of on-grade ditches is improved by burying perforated plastic drain pipe in the bottom of the ditch; 20-cm pipe would be adequate for most cases. Roads are another source of runoff that should be mentioned. Due to Mine Safety and Health Administration (MSHA) safety regulations regarding road berms, many roads become open conduits carrying large amounts of water. Large amounts of sediment may also be carried.

Disposal of this water and sediment is a problem for the industry. However, disposal of water within waste embankments has not been a significant problem for the industry. Where embankments are constructed by end-dumping from considerable height, the gravity sorting results in the coarser rock going into the base of the embankment. This size gradation apparently provides adequate drainage as there is no evidence of a water buildup in such embankments. Excessive pore-water pressures, if they ever develop, will probably come from a large rainfall event with a long return period.

Cross-valley fills are new to the Idaho phosphate mining industry. Only one such fill has been built, another is under construction. Both of these embankments will use the french drain or rubble drain to transmit streamflow through the base of the embankment. There are three concerns with french drains: (1) the capacity of the drain to transmit flood water, (2) the rate at which water can enter the upstream end of the drain, and (3) the possibility of the drain plugging with sediment at some time in the future. These concerns will be briefly considered.

Drain capacities are controlled by the size, or cross-sectional area, of the drain itself, the hydraulic gradient, and the transmissivity through the drain. With these in mind and with the intent to build drains with large capacity, we need to be sure that the drains are generously sized and constructed of coarse, durable rock. The cross-valley fill and french drain at the Conda Partnership's Dry Valley Mine appears to meet these guides. Although the hydraulics of this drain are still under study, the drain capacity is estimated to exceed 10,000 cubic meters per hour. The upper bound of the capacity is not known. At any rate, this is a substantial capacity.

The second concern, the rate at which water can enter the drain, is explained simply. In a large flood, say with a return period of 100 years or more, can all of the flood flow enter the drain simultaneously? If not, where does the rest of the water go? Even a drain with a substantial capacity may not be able to transmit a flood crest through the drain without any overflow. One possible solution to this problem is to truncate the upper end of the embankment. This creates a temporary reservoir that will hold the excess flood volume and drain it off over several hours or several days. This approach will make a large and significant reduction in the danger of a cross-valley fill being overtopped.

The danger of plugging a french drain with sediment does not appear to be large. However, it should be plain that the result of plugging would be catastrophic. The entire structure of 30 to 40 million cubic meters could be lost. In normal conditions of streamflow and sediment loads in streams, the life of a drain is expected to be long, thousands of years. But the vagaries of nature dictate that conditions will not always remain normal. A fire on the watershed above a cross-valley fill would put excessive sediment into the drain. One way to mitigate this is to cover the upstream end of the drain with one of the geotextile filter cloths. The temporary reservoir mentioned above will also tend to trap sediment. We all need a better solution to this problem.

SEDIMENT TRAPS

In the Idaho phosphate operations the most common method of trapping sediment is by use of the sediment pond. For the most part the ponds work well, trapping nearly all of the sediments with the exception of the colloidal particles and clays. Trap efficiencies have not been studied. However, due to the mountainous terrain and narrow valley bottoms, sediment ponds tend to be undersized with retention times that are too short. Sediment ponds also require such maintenance as dredging out when the pond is about two-thirds full. Sediment ponds on phosphate mines tend to be unmaintained or undermaintained. Research and development into sediment ponds that are easier to maintain and that increase retention times would be of significant benefit.

Other means of sediment control have been tried. One method that held some promise, at least on paper, of reducing cost while still trapping sediments was the gravel filter blanket. Experience with this means of sediment control has not been good and it cannot be recommended.

FLOODS IN SOUTHEASTERN IDAHO

Hydrologic phenomena are erratic in both time and space. Therefore, averages of hydrologic data tend to be misleading because the average is rarely realized. Usually the extreme event is of the greatest interest to society in general and to design engineers in particular. Flood frequency analyses of streamflow records help the hydrologist determine the potential flood risk and the design engineer to produce efficient designs for hydraulic structures, including waste embankments and drainage systems. However, this job is severely hindered by a lack of streamflow data. This creates uncertainty and inconsistencies between the results of different analysts and different methods. Part of the difference is due to the manner in which floods are conceptualized. In southeastern Idaho three flood generating mechanisms operate: (1) rainfall, (2) snowmelt, and (3) rain-on-snow (Kjelstrom and Moffatt 1981). In most years the peak flow, or annual flood, is generated by snowmelt. It also seems certain that the exceptionally rare flood (1000-year flood) will be generated by rainfall. Somewhere in between these extremes will lie the rain-on-snow floods. It seems reasonable to assume that the 100-year flood will be generated as a rain-on-snow event.

South Maybe Canyon is a small watershed that contains a perennial stream, Maybe Creek. This watershed is of interest because it contains a cross-valley fill of about 30 million cubic meters. The magnitude of floods traveling down Maybe Creek has been estimated 18 times. Depending upon the assumptions of the analyses and flood-generating mechanisms used, the estimates have been quite variable. Of these 18 estimates, 12 were estimates of the 100-year return period flood. The watershed area above the embankment is 430 ha. The range of estimates for flood volumes is from 2 to 53 hectare-meters. Five snowmelt floods were computed; estimates range from 2 to 5.5 hectare-meters depending on the estimate of the 100-year snowpack and the resulting melt. Two estimates of rain-on-snow yielded values of 14 and 16 hectare-meters. Based on channel geometry and capacity, 100-year estimates gave values of 5.5, 7, 8, and 9.5 hectare-meters. Finally, one rain-on-snow flood event that followed a hypothetical forest fire on the watershed yielded the 53 hectare-meters estimated flood volume. The great variation in these estimates is due to the difference in assumptions associated with each estimate.

However, the important point is not associated with the flood volumes, but rather is that if cross-valley fills are designed to impound/transmit approaches to hydrology and stability problems, we do not need to reinvent the wheel.

The following points are germane:

1. We need to investigate alternative practices for waste disposal. More specifically (a) angle of repose toe slopes on waste embankments at selected sites, (b) improved foundation preparation and keyways, perhaps combined with the point above, and (c) size of waste embankments--what are the tradeoffs between one large embankment or many small ones?

2. We need to investigate subsidence and creep in large waste embankments.

3. We need to begin research and development into a framework for evaluating the risk and uncertainties associated with the stability of large overburden waste embankments.

4. We need to investigate potential flood flows in ungauged watersheds and start discussions on the appropriate return periods to consider when planning for the drainage of mining disturbed lands.

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RECLAMATION STANDARDS AND OBJECTIVES

Tom Roederer, Deputy Regional Forester
Intermountain Region, Ogden, UT

As the need for phosphate and other minerals continues to expand, it is important we meet to share our concerns. I will discuss the standards and objectives for reclamation from the perspective of a land manager.

The state of affairs in reclamation is: "We are not farming as well as we know how to farm." We are not using our technology and know-how in many areas, and sometimes we miss the scientific approach.

I'd like to leave these points with you:

1. Mining is an interim use of the land. From the land manager's perspective, mineral activity involving a 30-year to 40-year operating plan is not out of the ordinary and is perceived as an interim use of the land. A mineralized area has a premining mix of uses, a period where mineral activity is part of the crop, and then a period of postmining where the land has other uses. The principal difference is time.

2. Reclaimed land is as much a result of mineral activity as is the ore. Thinking of reclaimed land as a result of a product of mining may be new to some of you. However, I suggest it is valid.

3. Large surface mining operations offer an opportunity to reshape and revegetate land to meet future needs. In other National Forest activities, we only alter the vegetation of the immediate surface of the land. In surface mining, however, we actually create new landforms--some of considerable size. This provides an unusual opportunity for the land manager. If we do it right, "we can have our cake and eat it too"--extract ore for today's needs and reshape the land for the future.

4. The direction for reclamation should come from long-range plans. Management direction for the postmining period is critical. At the outset of mining, we need to envision and decide what the end result will be. The Forest Plan should prescribe the mix of uses expected for both the mining and postmining periods. The planned reclamation needs to be designed to return the land to a prescribed condition accommodating the desired postmining use.

5. Site-specific reclamation objectives ensure that the reclaimed site supports Forest Plan direction. The reclamation objectives need to identify the specific mix of uses to be accommodated on the mined area. These may or may not be the same uses that were there before or during mining.

6. Performance standards ensure that reclamation objectives are satisfied. Standards are needed to ensure the desired end results for such factors as steepness of slope, amount of ground cover, water quality, and visual expectations. We need continuing support from the research community. Development of standards at some defined level of risk is needed to guide reclamation activity. Finally, we need to monitor and evaluate our reclamation efforts over the long term.

I challenge you to use this approach or improve on it by providing a better one.

MITIGATION OF LONG-TERM LOSS OF SURFACE RESOURCES: THE PURPOSE OF THE IDAHO SURFACE MINING ACT

Stanley F. Hamilton, Director
Idaho Department of Lands
Boise, ID

I would like to discuss the essence of the Surface Mining Act: what it's supposed to do, where it's working, where it is not working, and what I would like to see happen in the future.

In my opinion, there are three standards that all mined land reclamation projects must meet:

1. Public safety (gentle slopes)
2. Land surface stability (gentle slopes, vegetative cover)
3. Maintenance of water quality (gentle slopes, vegetative cover, reduction of erosion)

One major problem with the act is that certain operations were "grandfathered" when the law was enacted. An excellent example is the operation on State land called the Bovill clay pits at Bovill, ID. This site has been a scar on the landscape for years. It's not subject to the law, and the State lease, which predates the act, requires only a passing effort toward reclamation. Even if the project were covered by the act, it's doubtful if the reclamation could be done for the $750 per acre bond authorized by this outdated statute.

Therefore, I am pleased that Simplot Company, the operator of this lease, is voluntarily and at its own expense reclaiming this site. Simplot's work is to be commended.

The statutory bond limit of $750 per acre is a source of major concern to me, and each year that costs increase, the problem compounds. Right now, it's virtually impossible to reclaim small sites for $750 per acre. Nor could the Idaho Department of Lands handle any unusual chemical problems we might find in an inherited reclamation project.

I believe the bonding provisions of the Surface Mining Act are inadequate, and I seek your help in making them more reasonable in a manner similar to last session's changes in the Placer Mining Act.

Also, the exploration provisions of the Surface Mining Act are weak and need to be strengthened. An example of the problems we have encountered is the case of Abella Resources, a Canadian company that has been exploring for molybdenum on Scott Mountain, east of Garden Valley in Boise County. The company has simply walked away from its project without any effort to stabilize or restore the areas it disturbed--mostly roads not covered by the act. The Forest Service had a small $5,000 to $6,000 bond on the project that was barely adequate to water the roads and seed the slopes.

A similar project by Financial Design, a now defunct company from Boise, occurred about 18 miles east of Boise on Blacks Creek. The company was exploring for gold on Forest Service land in an area known to have low grade deposits. The company filed no plan or notice with the Forest Service and posted no bond. Virtually all of the work involved roads that were not covered by the Surface Mining Act. Before work began, the entire hillside was well-vegetated and stable. Road construction has caused extensive slope failure and subsequent denuding of the hillside.

To my mind, these projects demonstrate a clear need for more control over road construction activities in mining exploration projects.

Again, I seek your help in amending the law to deal more effectively with this type of activity.

One of the standards for a successful reclamation project is maintenance of good water quality. Properly constructed settling ponds are one way to achieve and maintain acceptable water quality.

Unfortunately, ponds that were at the Golden Reef Mine did not achieve that goal. In July 1981, Dewey Mines, predecessor to Golden Reef, had a major leak in its ponds resulting in excessive turbidity in more than 80 miles of Mule Creek, Monumental Creek, Big Creek, and the Middle Fork Salmon River. Dewey Mines, to its credit, worked hard to solve the problem. First, the company built additional ponds. Unfortunately, the liners sagged and leaked, and that avenue had to be abandoned.

When Golden Reef bought the mine, it completely redesigned the mill to significantly reduce the amount of process water needed. The company was successful enough that it was able to close the ponds and restore the land to near its original contours. The hill is relatively stable now, and water leaving the area is reasonably clear. All told, the company spent more than $100,000 in efforts to solve the leakage problem and reclaim the ponds. The State holds a $25,000 bond for the entire project.

Again, it's obvious additional bonding is required.

There also exists an apparent lack of authority to regulate reworking of old dumps and tailing piles. I understand that prelaw dumps and tailing piles are exempt from reclamation plans when the dumps are reworked. Such projects often involve many acres and much surface disturbance. I fail to see why such projects should be exempt from the law when new work occurs.

I seek your help in amending the law to authorize regulation of the surface effects of underground mines and the reworking of prelaw dumps and tailings.

Inspection fees are currently disparate with fees charged for inspecting placer mining operations. As you know, placer mining fees were recently changed and surface mine inspection fees should soon be changed to reflect equivalency.

The terms of the Surface Mining Act are no better than the enforcement that exists. Under my direction, the Idaho Department of Lands will provide firm, fair enforcement. We will almost certainly be aggressive in dealing with problems that "fall through the cracks" or are uncertain in terms of application of the law. The department will not be unreasonable in its enforcement activities.

In general, I believe that the terms of the Surface Mining Act are being met by the large mining companies, and their efforts are to be commended. On the other hand, the terms and intent of the act are not being met by many small miners and by many exploration operations. Nor are the objectives of the act being achieved at the surface of many underground mines or during the reworking of prelaw dumps and tailing pipes.

Mining is an important industry in Idaho, and we want it to continue as a viable and profitable enterprise.

The essence of the Idaho Surface Mining Act is the message:

BE A GOOD NEIGHBOR-- <u>CLEAN UP YOUR MESS!</u>

Our Department's mission is to ensure that the mining industry accomplishes that cleanup and in the process maintains public safety, land form stability, and good water quality.

PHOSPHATE LEASE FORMS, TERMS, AND STIPULATIONS

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Following the completion of the phosphate regional environmental impact statement on southeast Idaho phosphate, the Bureau of Land Management, the U.S. Forest Service, and the U.S. Geological Survey were faced with taking action on a variety of issues that included the 20-year phosphate lease readjustment and the preference right lease applications.

To begin action on the readjustments, the three agencies and industry representatives met in February 1978 at Pocatello to outline their strategy. The agency representatives agreed that a new lease form needed to be developed. A new phosphate lease form was issued by the BLM in September 1980. This form was never used in Idaho. A meeting in early 1981 covered the lease form, followed by the phosphate industry (through the Idaho Mining Association) submitting comments on the form in mid-1981. Another agency-industry meeting in fall 1981 covered the industry comments. A proposed phosphate lease form was developed, submitted to industry, and industry returned comments in mid-1982.

The decision then at the Washington level (Department of the Interior and the BLM) was to develop a "generic" lease form for solids minerals rather than proceed with a phosphate lease form. The generic lease form was published in the Federal Register in April 1983. Industry submitted comments on the generic form, and the final form was published in March 1984.

In March 1982, the BLM published proposed rules for the 43CFR Parts 3500, 3510, and 3520, mineral leasing regulations. In July 1982, industry submitted its comments. Because the lease form terms are drawn from the regulations, the new generic lease form and the leasing regulations were developed together. The final regulations were then published in April 1984, about 6 weeks after the lease form was published.

TRADEOFF EVALUATION: ACCUMULATIVE EFFECTS OF MINING AND POSTMINING LAND USES

Vaughn Francis, Forest Service District Ranger
Soda Springs Ranger District
Soda Springs, ID

From my District Forest Ranger's perspective, I will discuss three areas of concern about minerals management and mining activities: (1) tradeoff evaluation, (2) accumulative effects of mining, and (3) postmining land uses.

Some people, including myself, dislike the term "tradeoff." This is because of its negative connotation, that in a tradeoff situation there will be something lost or given up. In administering the National Forest system lands, I would rather evaluate the compatibility of the various uses and consider the ability of the ecosystem to adjust to the various impacts. Many activities even have a symbiotic relationship and actually are an asset to each other. Following are a few examples:

1. The cooperative wildlife-phosphate study actually found that mining impacts, although disruptive, are not entirely destructive, and that wildlife are capable of adjusting to mining operations.

2. A major impact in 1983 was the construction of a 26-mile long slurry line from the Smoky Canyon Mine (J. R. Simplot) to Conda, ID. Work was scheduled to avoid elk-calving areas during calving periods and to avoid major stream crossings during spawning or high water.

Mining activities, if planned properly and completed according to plans, need not be destructive to other values and resources but are in fact compatible.

On the Caribou, 20,000 acres of National Forest system lands are under phosphate lease. Many more acres are now being considered for lease. Individually, any one lease or mine area is not a significant impact, but when all leases are looked at, they could show a major impact.

For that reason, extra care must be given in several areas:

1. Special stipulations to meet known site-by-site needs must be included on lease stipulations.

2. Operating plans must be based on sound exploration data, including drilling, pits, and geology. Then the plans must be followed.

3. To lessen the resource impacts, one mine area should be completed, including rehabilitation, before proceeding to a new mine area.

4. Transportation needs are a major impact and should be planned thoroughly and carefully. Should conveyor belts, truck haul, railroad, slurry line, or some other method be used to gain access and transport ore?

Tom Roederer has talked about reclamation standards. I would like to add that postmining land use is occurring. Wildlife seek out and use the reseeded areas, often close to current, active mining operations. In 1983 we released the mining company of responsibility for two mine waste dumps and allowed the grazing permittee to feed the area with sheep. One major problem with grazing is that in many cases a beautifully

reclaimed area is adjacent to an area newly reclaimed and not ready for use.

We have enjoyed success in planting conifer trees on mine dumps. The middle waste shale seems to be a good medium not only for grasses and forbs, but also for brush and tree species. When fertilized for a few years to help get the soil organisms functioning and vegetation established, the shales then seem to break down nicely into a good growing medium.

Mining, when planned properly and when the plans are followed, is compatible with other resources and uses.

MINE PLANS: BASIC REGULATORY REQUIREMENTS

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Under the amended Mineral Leasing Act of 1920, as far as it applies to phosphate, no requirement exists for the submission of mining or operation plans. However, regulations from the Secretary of the Interior require that:

> Before conducting any operations under a permit or lease, the operator shall submit, in quintuplicate, to the authorized officer for approval, an exploration or mining plan which shall show in detail the proposed exploration, prospecting, testing, development, or mining operations to be conducted . . . . No operations shall be conducted except under an approved plan.

These regulations are in Title 43 Code of Federal Regulations, Subpart 3572. Prior to August 12, 1983, they were found in Title 30 CFR Part 231. The change was due to the 1982 merger of the Bureau of Land Management and Minerals Management Service and the resultant recodification of parts of Title 30, Mineral Resources, to Title 43, Public Lands: Interior.

The 43 CFR Part 3500 regulations apply to the solid leasable minerals other than coal. Specifically, these minerals are potassium, sodium, sulfur, gilsonite, phosphate, and the acquired-lands hardrock minerals. These regulations also apply to Indian reservation lands in concern with Title 25 CFR. Significant operations currently covered by the regulations are the trona deposits in Wyoming, potash deposits in New Mexico, the lead-zinc deposits in Missouri, and phosphate deposits in Idaho. Because of this diversity, the regulations are general and provide a lot of latitude to the authorized officer as to what he or she deems an acceptable mine plan for a particular deposit.

An integral part of mine plans are maps. While the regulations do not specifically include the map requirements under the operating plan section, they do address map requirements on an as-required basis.

The mine plan, including maps, is reviewed and approved by the authorized officer after consultation with the other involved agencies, usually the Forest Service or Bureau of Indian Affairs. If modifications of the plan are required, the regulations provide that the authorized officer will indicate what these are in order to make the plan acceptable.

To eliminate misunderstandings and undue time delays, the operator should develop a preliminary mine and reclamation plan for review and discussion purposes with the authorized officer and other appropriate agencies. This in the long run will save time and heartburn for all parties involved.

THE COMPUTERIZED MINE PLANNING PROCESS: STATE OF THE ART

Treve Hocking, Principal Mining Engineer
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Use of computers is fast becoming standard practice and has largely replaced manual effort in mine planning. Most of the programming is based on manual methods. The advantage of the computer over manual methods is speed, allowing rapid analysis of alternates. This in turn allows timely evaluation of multiple operating options in developing mining plans.

MODELING

The first step in computer application to a given deposit is to develop a mineral inventory model, sometimes called a geological reserve model, of the mineralized zone. Various methods are applicable and the net result is a mathematical description of the ore body suitable for evaluation of ore quantities and grades in relation to a particular geometry for mining.

This model, of course, attempts to represent reality, optimization processes applied to it will optimize the model and not necessarily reality.

ESTABLISHMENT OF MINABLE ORE RESERVE

The ore reserve is that part of the mineral inventory that can be mined at a profit. This requires establishment of economic pit limits. The most common methods used are:

1. Break-even stripping ratio.--This is production value minus production cost of ore divided by the stripping cost per ton of waste.

2. Cut-off grade.--This is the lowest grade at which an ore body can be profitably exploited.

3. Ultimate pit mining slopes.--Established from experience or geotechnical studies.

Use of computers in this process can be interactive between engineer and computer, or automated. The lastest advances are in interactive engineer-to-computer graphics applications. When these become more widespread they should replace the present systems.

LONG-RANGE PLANNING

Long-range planning supplements the ore reserve and ultimate pit design plans. It relates the geometry of mining to the ultimate pit limit by creating phase designs. These are shape-oriented rather than time-oriented. The phase designs are then used as a basis for long-range time-oriented mining plans. The long-range plans quantify the amount of waste stripping required to maintain ore continuity at the required grade. These plans are probably annual for the first 5 years and for longer periods until the ultimate pit limit is reached.

SHORT-TERM PLANS

These are for less than 1 year. Here, computers allow detailed equipment and production scheduling and budget preparation.

The primary problem in short-term mine planning is the large number of interrelated factors and the time-consuming calculations. Use of computers, usually associated with graphic digitizers or interactive terminals, allows fast calculation and permits rapid revision for changing operating conditions.

PHOSPHATE MINE WASTE DUMP LOCATION, DESIGN, CONSTRUCTION

Ed Connors, Mining Engineer
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Waste disposal is one of the most, if not the most, costly operations in open-pit mining. In the Idaho phosphate field, 6 to 9 tons of waste must be moved for each ton of ore produced. Dumps must be constructed to be permanently stable and vegetated to minimize erosion, and material eroded must be contained on site.

I. Site Selection

A. Alternative sites needed to comply with National Environmental Protection Act (NEPA) regulation, should be selected and proposed by operator

B. Selection criteria

1. Operators: a. haul distance, b. relative elevation, c. capacity, d. foundation stability.

2. Surface Management Agency (SMA)

a. Impacts on surface resources: water, wildlife and wildlife habitat, timber, range, recreation, esthetics, socioeconomic, and threatened and endangered species.

b. Amenability to revegetate: stability, slope, mantle of middle waste shale and topsoil.

The SMA makes its selection through the NEPA process using one of three approaches: categorical exclusion (CE), environmental assessment (EA), or the environmental impact statement (EIS). The scope and magnitude of expected impacts dictate which must be used. Mine waste dumps as part of a mining plan are usually addressed in an EA.

II. Dump Design

A. Clearing

1. All merchantable timber, poles, and posts will be timber harvested. All other trees within dump site are to be cut. Harvest of firewood is urged.

2. A barrier of slash is to be built at final dump toe in each drainage channel.

3. Grubbing and removing of other vegetation are not required.

4. Normal accumulations of snow need not be removed.

B. Drainage

1. For beneath dump drainage, continuous rock drain leading to the final toe of the dump must be constructed in drainage channels within the dump site.

2. Surface flow entering the dump site must be provided an adequate and permanent channel under, over, or around the site.

3. The top surface of dumps must be constructed so as to direct surface flow away from the steep faces to some safely controlled means of disposal.

C. Placement of waste rock

The Forest Service has three major concerns in the placement of waste rock:

1. Only coarse durable rock will be used in drainage structures or channels.

2. Dump surfaces will be covered with a minimum of 5 feet of waste shale as a plant growing medium.

3. Mass stability of finished dump is accomplished.

There are two schools of thought. The civil engineer's approach is to build either an earth fill dam or a highway fill. Waste would be placed in shallow layers starting at the bottom and compacting each layer in sequence. This approach is not compatible with the characteristics of waste rock. It would be excessively costly. The end use does not warrant such stability as could be achieved.

The miner's approach is to dispose of waste rock in the most economical and safe way possible within the constraints of the equipment used and the topography. A scraper operation would lay down relatively shallow layers with the only compaction being incidental to the movement of the scrapers. A shovel truck operation may dump waste rock from a single high level or by dumping on a series of levels usually starting with the highest level. The only compaction obtained is incidental to the trucks and other equipment operating at the dumping levels.

The Forest Service has no quarrel with the miner's philosophy of waste dump construction when the three conditions mentioned earlier are met--provisions for drainage and for mass stability and a surface cover of shale as a growing medium for vegetation.

D. Final shape of dumps

1. The Caribou National Forest has a policy with two simple requirements for the shaping of waste dumps. These are easily understood and readily monitored.

   a. The dump face will have no concave surfaces, avoiding concentration of runoff and consequent erosion.

   b. The dump face will not be steeper than 3 horizontal to 1 vertical. This will:

      (1) Permit use of agricultural type of equipment in seedbed preparation, fertilizing, and seeding.

      (2) Permit equipment to move on the contour and thus minimize the potential for erosion.

      (3) Automatically present a high degree of mass stability.

2. Industry has a fundamental problem with the 3:1 slope:cost of shaping.

   A dump face slope of 2.5 horizontal to 1 vertical is about as steep as can be ripped, harrowed, fertilized, and seeded using currently available equipment. However, at this slope the equipment can move only up and down the slope, setting up ruts that channel runoff water and promote erosion.

   The Caribou has stipulated that finished slopes will not be steeper than 3:1 because:

   a. Ripping, harrowing, fertilizing, and seeding can be done on the contour, setting up ruts that inhibit channeling of runoff and enhance infiltration.

   b. Greater mass stability is obtained with a 3:1 slope than with a 2.5:1 slope.

   c. Cost per acre for revegetation is less than for steeper slopes.

   A comparison of effort needed to shape an angle of repose dump to a 3:1 slope is shown in sketches 1, 2, and 3. These sketches use simplified geometry to establish a relationship that will be valid in the more complicated geometry that the miner will encounter.

Sketch 1: A vertical, longitudinal section through a waste dump at a uniform angle of repose of 1.4:1.

Sketch 2: Same section shaped to 3:1 slope required by the Forest Service. The effort required for the shaping is calculated and equated to 100 percent for comparison with other slopes and conditions to follow.

Sketch 3: The same section shaped to 2.5:1 slope. Here the shaping effort is calculated to be only 72 percent of that required for the 3:1 slope.

III. Means of Reducing Shaping Costs

A. Dumping on decline.--Sketch 4 shows a 10 percent decline of the dumping level from the point where the 3:1 slope intersects the dumping level out to the angle of repose slope. The shaping effort calculates to be 80 percent of that shown in sketch 2.

B. Saurman dragline system.--Sketch 5 shows the range of bucket-travel up to 1,000 ft, buckets to 20 yd^3. Advantages: (1) only bucket travels, creating less energy waste, (2) less inhibited by weather and wet material.

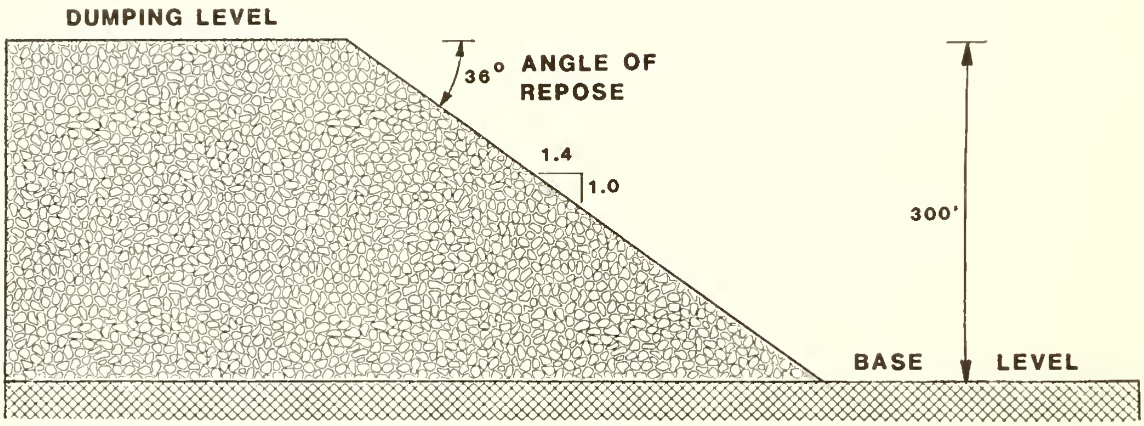
Disadvantages: (1) capital costs, (2) lack of mobility, and (3) lack of opportunity to keep in service year around.

C. Induced failure by water injection.--Sketches 6 and 7 show a proposed experiment that would require the combined talents of an experienced hydrologist and geotechnical engineer and a cooperating mining company. A bench would have to be cut at some calculated point in the progress of dump construction. Pipeline would have to be engineered to evenly distribute the water. Waste in which hydrostatic pressures could be built up would need to be placed in the vicinity of the distributor pipe and so forth. When all of the waste is in place, then water would be pumped in to create a condition of saturation that would induce failure. Sketch 7 shows concept of how profile might look after failure.

D. Planned placement.--Sketch 8 shows a waste dump planned for the head of a hollow and having convex contours on the face of the dump. Sketch 9 shows the outline of the finished dump superimposed on the original topography. Sketch 10 shows where the angle-of-repose crest should be located to minimize the effort required to shape the dump to the planned configuration. This crest line was located by drawing a series of vertical sections normal to the final crest, down to the original topography, and out to the final toe. The position of the angle of repose crest was adjusted on each section until the cut and fill were equal.

CONCLUSION

Each of the four suggestions in Section III may have potential for cost reduction. Perhaps by using variations or combinations of these suggestions, industry could accomplish its desired cost level while producing the 3:1 slope desired by the Caribou National Forest.



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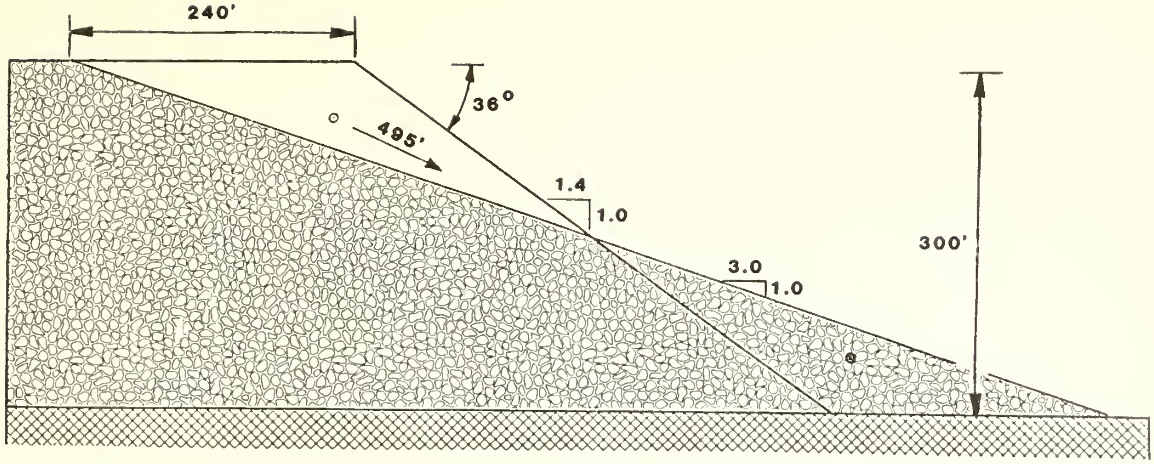
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3.0
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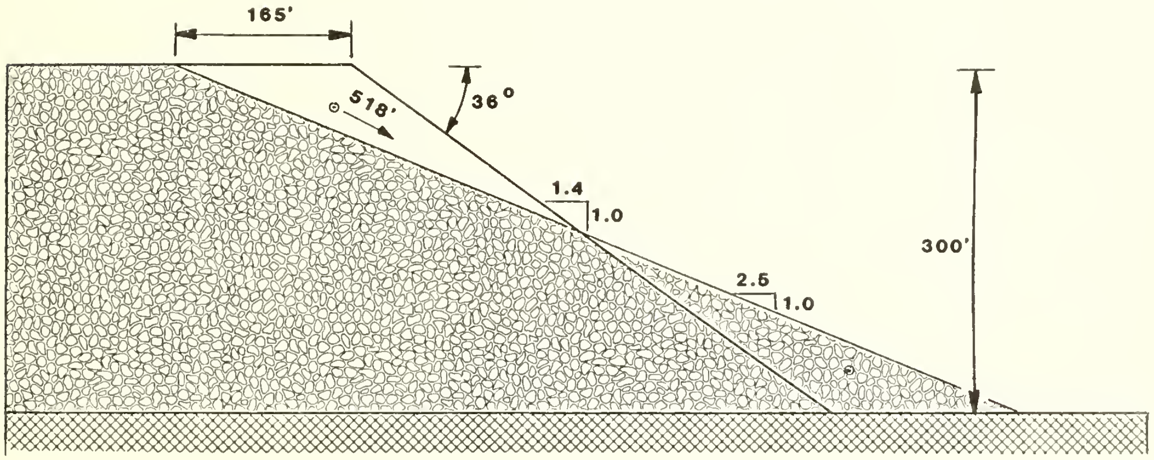
2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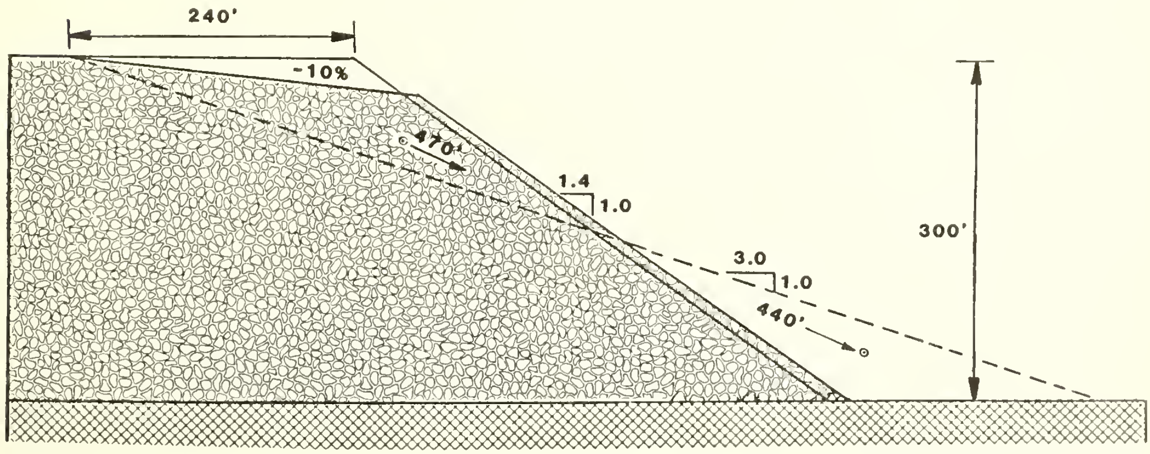
3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-10%
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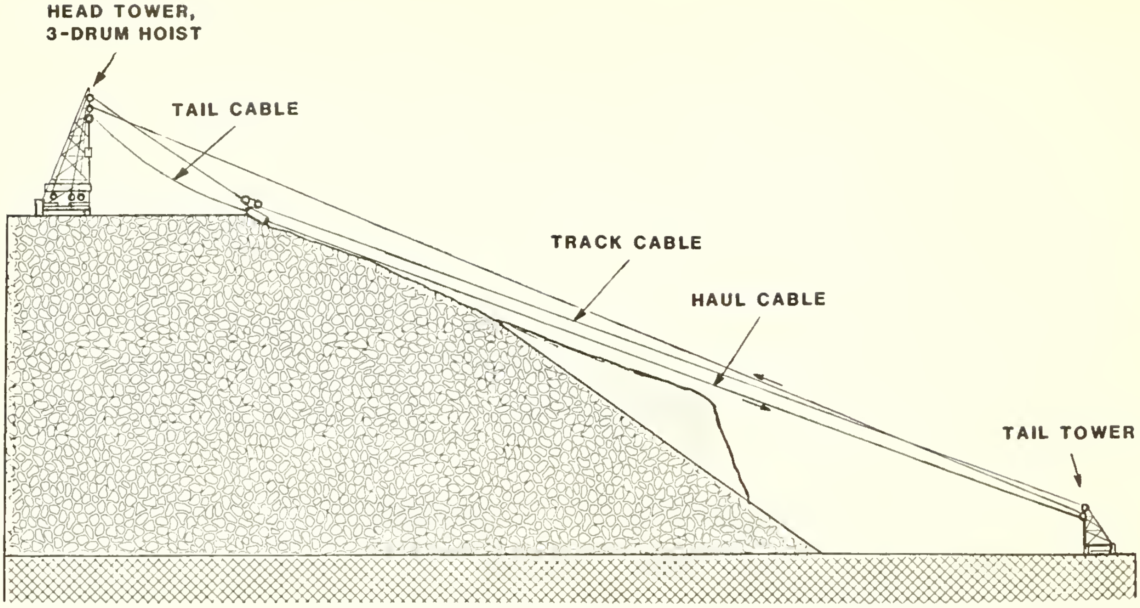
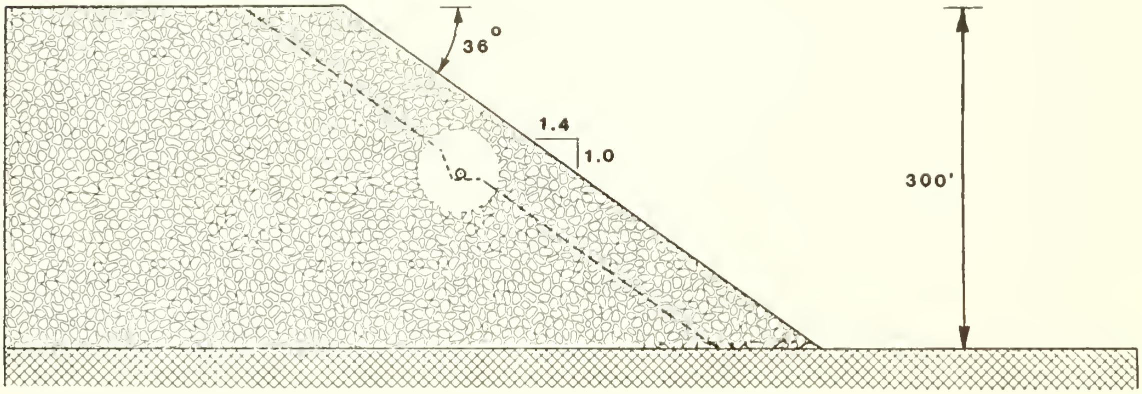
1.4
1.0
3.0
1.0
440'
300'

4


HEAD TOWER,
3-DRUM HOIST
TAIL CABLE
TRACK CABLE
HAUL CABLE
TAIL TOWER

5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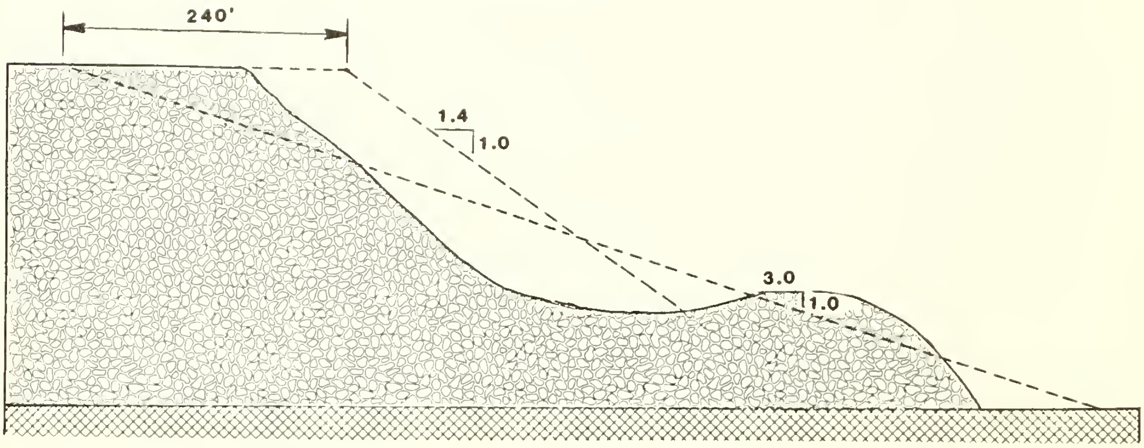
240'
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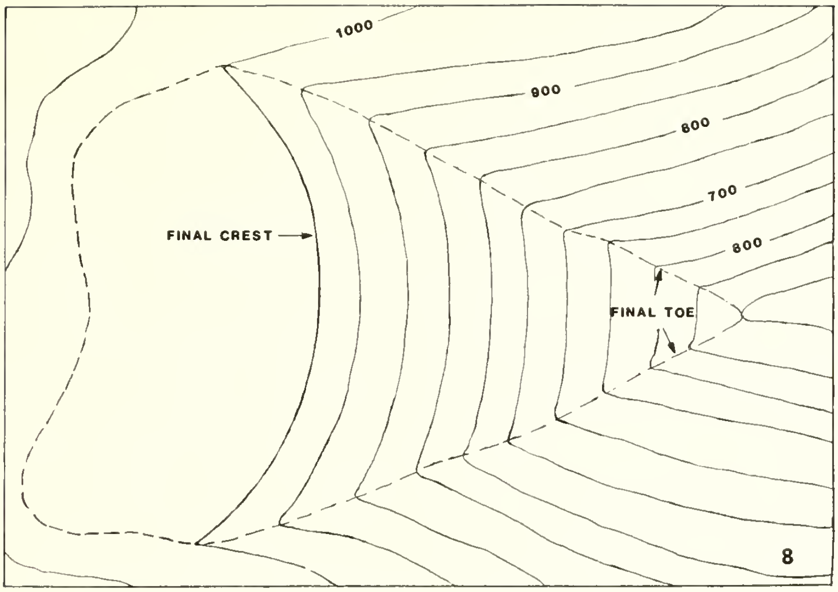
1000
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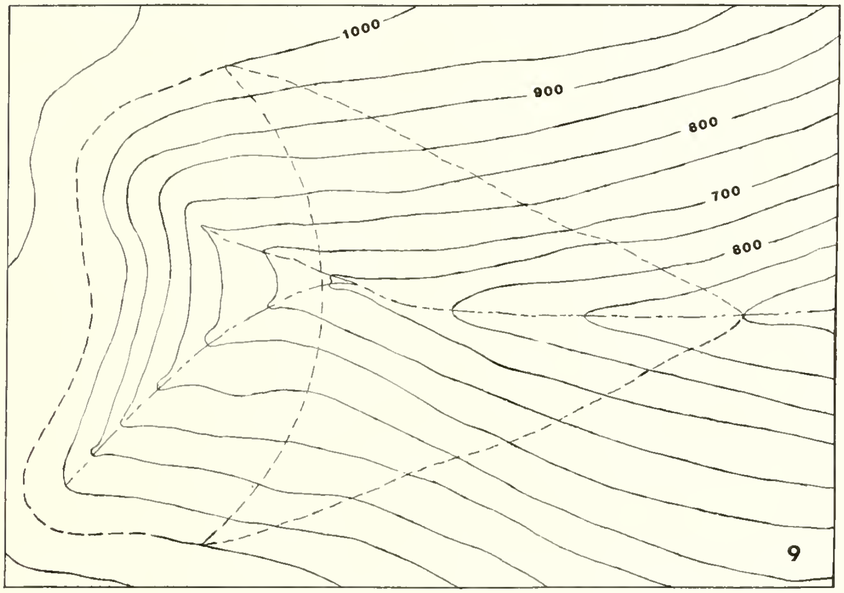
FINAL CREST
FINAL TOE

8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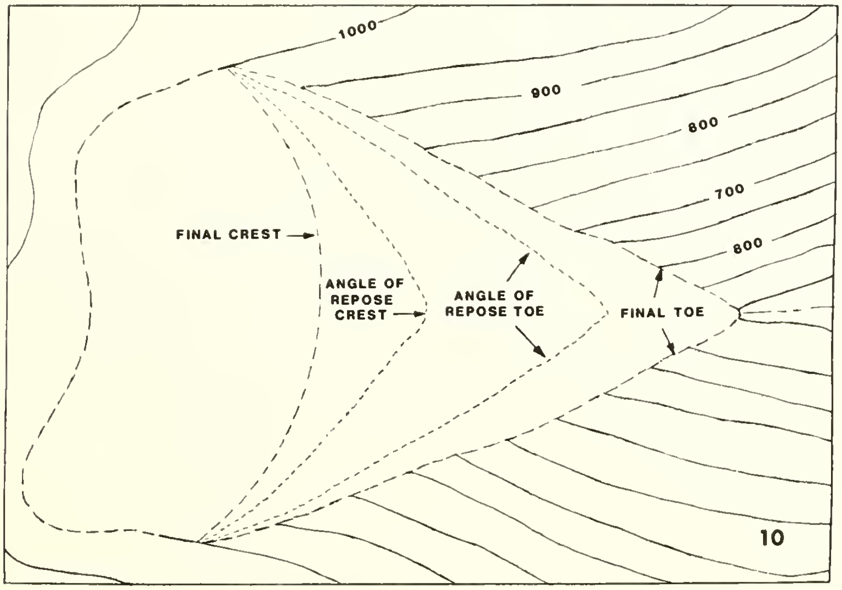
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FINAL CREST
ANGLE OF REPOSE CREST
ANGLE OF REPOSE TOE
FINAL TOE

10

RISK ANALYSIS: STRUCTURAL FACTORS

Loren R. Anderson, Associate Dean
College of Engineering
Utah State University
Logan, UT

Despite the care taken in siting, designing, and constructing an earth dam or other civil works structure, a residual level of risk of a catastrophic failure will remain. The event that causes the failure may be natural such as a flood or an earthquake, it may be related to the structure itself such as uneven settlement, core cracking, piping, or embankment of foundation slips, or it may be related to human factors such as incorrect operation or acts of war.

Following the Teton Dam failure of June 5, 1976, the civil engineering profession realized it had fallen behind other engineering disciplines in the application of risk and reliability analysis. However, the direct application of the procedures developed for risk analysis in the manufacturing industries, where many identical items are produced under conditions conducive to strict quality control, are generally not applicable to civil engineering projects.

The successful practice of geotechnical engineering requires judgment based on a knowledge of precedent as well as on understanding the principles of soil mechanics and geology. This fact is often used to support the argument that risk analysis and probabilistic methods have no place in geotechnical engineering. The opposite conclusion should be reached. Probabilistic methods and risk analysis have been developed specifically to cope with uncertainty in a rational way. Risk analysis procedures can be useful even when the design involves making many decisions for which some are based on analytical procedures, some on empirical procedures, some using precedent-based design rules, and some using strictly engineering judgment. Probabilistic methods are available that can consider uncertainty involving a judgment decision and include it in the same probabilistic analysis that considers the uncertainty in an analytically based decision.

A major area of geotechnical engineering for which the use of risk-based analysis procedures would be helpful is that of selecting between alternatives, whether it be for selecting alternative designs or for selecting alternative methods for mitigating a hazard. In the case of selecting an alternative, the problem involves evaluating the relative risk of the alternatives rather than the absolute risk. As an aid in selecting alternatives, risk analysis can be applied at all stages of project development from the initial feasibility studies through construction and into operation and maintenance. As the project progresses the data base for making risk assessment grows and the ability to evaluate risk increases. An absolute assessment of risk for a project as complex as an earth dam won't likely be possible for some time, if ever. However, a relative assessment of risk is all that is needed for selecting the best alternatives. It can help an experienced engineer determine whether an investment to improve one part of a complex structure will significantly reduce the overall probability of failure of the structure.

Figure 1 illustrates a risk-based method for establishing priorities for alternative dam safety improvements. The same general framework would also apply for selecting between alternatives for other types of structures such as waste embankments.

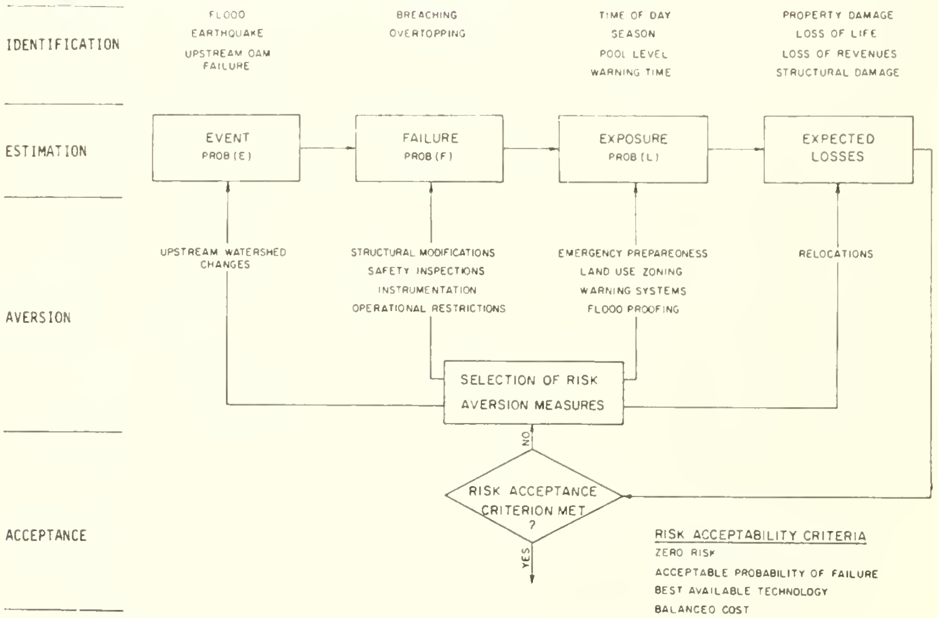

Figure 1.--Risk-based method for establishing priorities for alternative dam safety improvements.

HYDROLOGIC UNCERTAINTY AND RISK IN THE IDAHO PHOSPHATE AREA

Richard H. Hawkins, Professor of History
Utah State University, Logan, UT

Dan J. Kotansky, Graduate Student
Utah State University, Logan, UT

Eugene E. Farmer, Project Leader
Intermountain Research Station
Logan, UT

Hydrologic risk covers two major categories: first, technical uncertainty, which is not knowing what will happen; and second, probabilistic risk, which deals with not knowing when an event will happen.

In the phosphate area, technical uncertainty arises mainly from three phenomena: (1) errors in estimating remote events due to the unsuitability of available technical methods; (2) insecurity about the source processes of remote events, which can possibly lead to an unappreciated scale of flood flows; and (3) uncertainty on the altered hydrologic nature of mined lands and watersheds.

Available methods of estimating remote floods on ungauged areas are generally based on rainstorms. The techniques in vogue have been derived largely for eastern agricultural settings. Their suitability on western forest and range lands (and mined sites) has not been demonstrated. In fact, there is a growing body of evidence that they are unsuitable. A similar unhappy situation exists in the extraction of long-term sheet and rill erosion for western forest and rangelands. Also, there is not general, convenient, and well-developed techniques for estimating annual snowmelt floods from ungauged watersheds. Finally, the plethora of methods available and the information choices give a wide variety of answers. For the case of South Maybe Canyon, estimates of 100-year flood ranged from 17 to 436 ft^3/s, with a median of about 82 ft^3/s.

Source area processes in the uplands of the Intermountain West are important because of the vast differences in floods from snowmelt and rainstorms. Most annual floods arise from snowmelt and are of modest intensity because they are limited by snowmelt rates. However, extreme floods are often triggered by rainstorms and may be larger than an equivalent return snowmelt event by a factor of 10. Estimates of extreme floods drawn from analysis of short duration records that contain only snowmelt events, can lead to erroneous low figures and consequent underdesign.

Mined lands have altered hydrologic characteristics, such as depth, texture, cover, and composition, leading to altered infiltration capacities. For example, spoil placement in cross-valley fills creates new lands of unknown hydrologic characteristics. Experience thus far shows that while hydrologic responses from the lands are generally unpredictable, these new lands are surprisingly conducive to rainstorm runoff. The findings have been counterintuitive and contrary to design assumptions.

Probabilistic risk concerns the occurrence of an event within a given period. It is a realistic deeper look at the expected probability of a return event, lending itself easily to subjective decision making. Three illustrations may be given. First, a 100-year flood will not necessarily occur within a given 100-year period. Indeed, the probability of it happening is only about 63 percent. Second, to be 95 percent sure of including a 100-year event in the life of a project (or a hydrologic sample), a period of about 300 years should be planned! Third, to be 90 percent certain of not exceeding the capacity of a structure on a 25-year project life, a return event of about 240 years should be used. Such elementary approaches may be used in planning, designing, and administering to realistically appreciate the risk of proposed actions.

Of the above-described problems, the most fruitful research areas are the source area processes and the hydrologic nature of mined lands. These are more specific to Idaho phosphate lands, and solutions would be directly applicable.

SEISMIC RISK: MONITORING/RESEARCH NEEDS FOR EARTHQUAKE SURVEILLANCE

Walter J. Arabasz, Associate Director

Robert B. Smith, Director
University of Utah Seismograph Stations
Salt Lake City, UT

Two factors directly impact any seismological capability for providing detailed earthquake information relating to phosphate-mining areas in southeastern Idaho.

First, figure 1 shows seismic stations covering the southern Intermountain seismic belt. The phosphate mining area lies within a distinct "hole" in the distribution of seismic stations. (The "hole" chiefly affects the threshold of perceptibility, focal-depth control, and ability to provide continuous event detection.) What regional coverage does exist is the result of efforts by the University of Utah to integrate continuous seismic data from the university's Wasatch Front seismic network with data from stations operated by the Idaho National Engineering Lab, by Ricks College, and by an operator in southwestern Wyoming. Approximately 80 seismic stations are operated or recorded by the University of Utah, providing regional seismic coverage of the Intermountain seismic belt between Yellowstone National Park (stations

not shown) and southern Utah. Data are recorded and analyzed centrally in Salt Lake City in a computerized central recording laboratory.

Second, there has been a distinct lack of resources available for addressing earthquake problems in southeastern Idaho. For example, funding is currently provided to the University of Utah by the U.S. Geological Survey (chiefly for attention to the densely populated Wasatch Front urban corridor of north-central Utah), by the State of Utah (for seismic surveillance of the Utah region), by the U.S. National Park Service (for Yellowstone Park), and by the U.S. Bureau of Reclamation (for monitoring a specific proposed damsite east of Salt Lake City). Funding from Geological Survey as part of the National Earthquake Hazards Reduction Program is constrained by Federal guidelines relating to high-risk urban areas (the Wasatch Front), and State funding from Utah requires appropriate application to the Utah region.

The State of Idaho and Federal agencies with specific interests in earthquake-related problems in that state have to date shown little interest in fostering earthquake surveillance or studies in southeastern Idaho. Some past efforts by researchers at the university have been funded by the National Science Foundation (such as 1977 to 1978 studies by Bones and Arabasz in the Soda Springs area) and by Geological Survey (such as a special study of the 1982 swarm earthquakes near Soda Springs).

Although special earthquake studies have been pursued in the past in southeastern Idaho for academic interest or because of a justified response to significant earthquake activity, continuous surveillance demands the commitment of stable, long-term support from interested user groups. Earthquake monitoring invariably involves significant costs that can't be "bootlegged" indefinitely. Realistically, local "users" in southeastern Idaho must initiate any call for action and resources to augment local earthquake monitoring.

A wide range of possibilities exists for improving earthquake data acquisition and for fostering specific studies aimed, for example, at engineering applications or risk assessment in southeastern Idaho. Required funding similarly has a wide range (from a few tens to hundreds of thousands of dollars). If at some point there appears to be firm intent or resolve to address specific needs, seismologists at the university will gladly provide assistance or further detail. At a minimum, there appears to be a clear need for adding at least two or three seismic telemetry stations to fill the southeastern Idaho "hole."

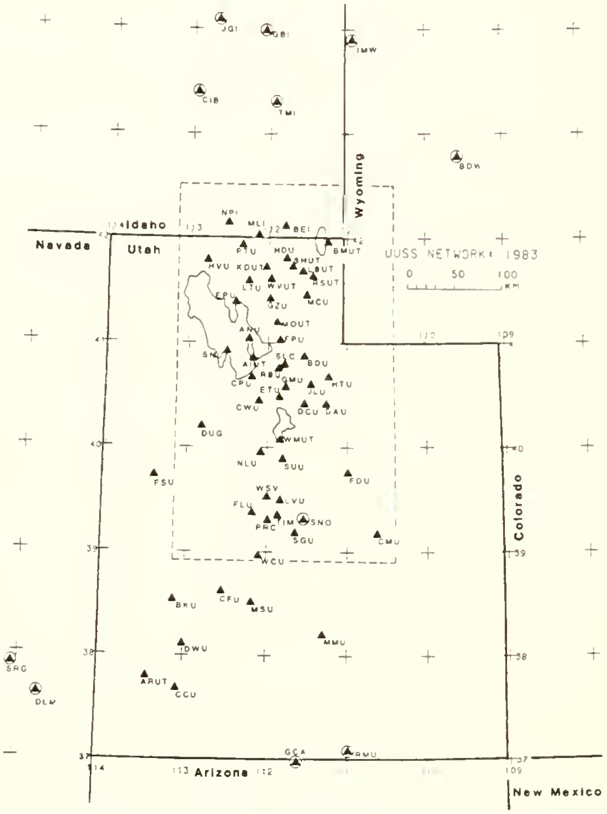

Figure 1.--University of Utah seismic network, February 1983. Triangles represent stations operated and recorded by the University of Utah. Circumscribed triangles represent stations maintained by other agencies.

RISK ACCEPTANCE

Eugene E. Farmer, Project Leader
Intermountain Research Station
Logan, UT

We all accept risk as a part of our everyday lives. But no one willingly accepts risks without commensurate benefits, and we all like to be aware of the risks that we accept or assume. In minerals extraction, both industry and land management agencies accept risk. Benefits also accrue to society, industry, and the government agencies.

How does the Forest Service accept risk? Risk acceptance by industry differs from the Forest Service both qualitatively and quantitatively. The risks are those structural, hydrologic, and seismic events that pose the danger of massive failure, overtopping, or severe soil erosion on overburden waste embankments.

While Forest Service managers take risks, we do not have a program for the analysis of risk. We have both formal and informal methods for qualitatively identifying a variety of risks. The formal methods, arising from the National Environmental Policy Act, are the environmental impact statement and the environmental analysis. The informal methods are developed through the process of reviewing mining plans, on-the-ground reviews by multidisciplinary identification teams, and the individual application of both practical and theoretical knowledge.

The Forest Service manages risk primarily through applying mitigating measures. These measures usually influence the length of the period that a projected impact may be active, or the location, and thus the severity, of the impact. Proposed mitigating measures are also given serious consideration from the viewpoint of cost to the operator and overall mine economics.

However, these methods of managing risk do not constitute risk analysis. In the context of managing risk through the application of mitigating measures, the real questions of risk and uncertainty are out of context and moot. For example, it makes little sense to ask a Forest Service land manager what is the design life of a given cross-valley fill, or to inquire about the design flood that will overtop the fill.

I believe that mine operators view risk quite differently from the Forest Service. First, the operators tend to be more quantitative. The design of waste embankments is frequently accompanied by a structural analysis of the factor of safety. This may or may not include seismic factors or other perturbations that relate driving forces to resisting forces. The semiquantitative factor of safety analysis is at the next level above the qualitative analysis of the Forest Service but still falls short of an analysis of the true risk and uncertainty. Second, mine operators must consider the price of their product in relation to the world and domestic market prices. These considerations usually dictate that waste embankments be constructed at the least cost. Finally, mine operators have a shorter time of responsibility for the developed mine lands, usually less than 20 years. Postmining land uses into the foreseeable future revert to the land managers.

Before the Forest Service can accept risk in a quantitative manner, we probably need: (1) a flexible national policy that can accommodate the changing technology, the likelihood of changing national preferences, and the possibility of changing institutional arrangements; (2) site-specific objectives developed at the local level with broad local agreement; and (3) reasonable performance standards that reflect true risk and uncertainty.

MANNER OF MATERIAL PLACEMENT: ROLLING HILLS AND PIT BACKFILL

Gordon Duncan, Mining Superintendent
Monsanto Company
Soda Springs, ID

The major landforms used for mining waste piles at Monsanto's Henry Mine are discussed, as are the waste pile design parameters, the method of construction, and the equipment used. Examples of each landform are presented along with advantages and disadvantages of each.

ANGLE OF REPOSE AND REGRADING

George C. Toland, Managing Partner
Dames and Moore
Salt Lake City, UT

I speak as a geotechnical engineer and not as an expert in land form construction or costs. My involvement with Simplot's flattening angle-of-repose slopes was requested because of three requirements proposed for the company's old dump by Federal, State, and private ownership. These requirements were: Federal--3 horizontal to 1 vertical; State--2.5:1; and private land--1.3:1. Our evaluations were not extensive but did involve embankment stability, erosion comparisons, and vegetation requirements.

Essentially, I believe there is no right or wrong answer to mine waste slope design. Mine waste embankments are like roadway embankments in that surface saturation is expected to cause problems. However, on roadway embankments I don't hear people suggesting 3:1 highway slopes, mainly because 90 percent of the mountain roads could

not be built at that slope. Reshaping mine waste on steep hillside areas has the same problem. There are many areas where the slope of the hillsides is steeper than 3:1.

These discussions lead to the conclusion that individual operations require individual design, and that abandoned dumps should be treated differently from new or continuing operations.

Two technical evaluations of the Idaho phosphate mine waste dumps deal with stability: the 1978 report by Utah State entitled, "Engineering Properties and Slope Stability and Settlement Analyses Related to Phosphate Mine Spoil Dumps in Southeastern Idaho," by Richard E. Ryker, Loren R. Anderson, and Rowland W. Jeppson; and "Stability of Non-Water Impounding Mine Waste Embankments," by Bruce C. Vandrey, published in 1980. Considerable data were developed in these publications, but they do not present a usable method for determining requirements for individual mining operations. Our evaluation for Simplot developed the stability and vegetation requirements for flattening to slopes of 2:1, 2.5:1, and 3:1. Our recommendations stated that a 2:1 slope appeared the best solution. However, I believe that angle of repose is the proper solution for most of the existing dumps at Conda.

The major concerns are cost and method of changing slopes from angle of repose to flatter slopes. Figure 1 shows the requirements to change to a 2:1 slope. Figure 2 shows requirements for changing to a 3:1 slope. You can see with a 2:1 slope you have to push material horizontally half the height of the slope, and with a 3:1 slope you must push the material horizontally a distance equal to the height of the slope. You can also see that I flattened the base of the natural hillside. This was necessary because in some locations you would need to flatten the hillside as well as the dump to achieve a uniform flattened slope.

Cost is difficult to assess. The use of a dozer to move material is economical to a certain push length. Beyond that, length scrapers or truck haul becomes more economical. Costs on moving mine waste are quite low by the yard, but by the millions of yards costs represent a major investment to mining companies with inactive dumps.

There seems to be only one item of concern with angle of repose dumps: continuing maintenance. The danger to the public is many times less than mountain road embankments. Therefore, the method of obtaining long-term maintenance seems to be the problem that needs solving. Some States have used maintenance bonds. A bonding requirement that reduces as the final slope decreases might be a long-term solution to the slope steepness requirement.

SLOPE REQUIREMENT

2 HORIZONTAL TO I VERTICAL

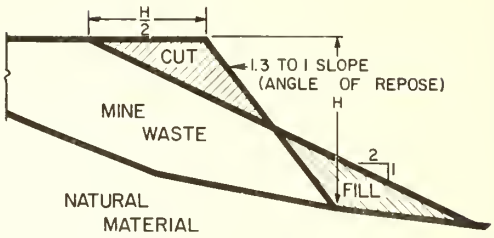

FIGURE I

SLOPE REQUIREMENT

3 HORIZONTAL TO I VERTICAL

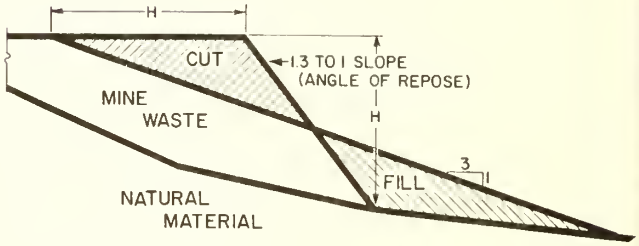

FIGURE 2

VALLEY FILL DUMP

Jim Frost

Donald D. Smedley
Mine Superintendents
Conda Partnership
Conda, ID

Whenever mining occurs, there are two resultant products: ore and waste. When mining was started on the southern portion of the I-04 lease, the disposal of waste rock presented a problem. This north-south striking ore body had only two disposal directions. The westward disposal would infringe on an elk calving ground that lies at the valley floor to the west of the lease, while Maybe Canyon to the east contained live water with several small springs. A waste rock storage area to the east was selected for a 30 MM BCY disposal site.

As live water would have to continue to flow beneath this structure when completed, a chert causeway was started by natural selection of elevated end-dumping to create a french drain that would ensure continued water filtration under the dump in the future. As this causeway approached the valley floor, a roll or "pooch" of alluvial/colluvial material was pushed in front of the advancing toe of the causeway. This roll could be partially attributed to saturated alluvial/colluvial material and the underlying Dinwoody Formation (a grey marlstone or shale). There was a concern that this roll would create a barrier to free flowage beneath the dump. The decision, in consultation with the regulatory Federal agencies, was to lay "in place" a chert core along the axis of the valley to further insure that water would not be impounded behind the structure and that the waste rock storage structure would not become saturated. This chert core was lain "in place" in advance of the continued elevated end-dumping as a french drain was placed on top of the chert core.

As the waste rock disposal area reached its ultimate height, the Intermountain Research Station began to conduct on-site research, co-funded by the Conda Partnership. This research included meterological data, piezometers and a well to determine porosity, neutron soil probes to detect any saturation, and stream flow gauge.

The research to date shows that water is flowing through and under the South Maybe waste rock storage area.

The cost of constructing an "in place" chert core was well above the per-BCY cost of the rest of the waste rock storage area. Because of an increased haul distance, the placement of 1 MM BCY in the chert core cost an additional $400,000, thus increasing the total mining cost for this open pit.

The Intermountain Station has provided valuable research showing that water is flowing through and under the South Maybe storage area, and that the structure has remained stable. Each waste rock storage area that is built will have different environmental and economic constraints that must be evaluated. Further study will be of value.

WASTE DISPOSAL EQUIPMENT: USAGE AND COSTS

Wayne L. Myers, Mine Manager
Gay Mine
J. R. Simplot Company
Pocatello, ID

All equipment discussed in this paper is currently in operation at Gay Mine. The J. R. Simplot Company's Gay Mine is within the Fort Hall phosphate district, one of 10 such districts in the Idaho phosphate field. The phosphate ore comes from the basal Meade Peak member of the marine Phosphoria Formation. Two grades of ore are mined and sent to the processing plants near Pocatello.

Because of the relatively small size of a typical fault block ore deposit at Gay Mine, there are usually two or three pits at various stages of mining at any one time. The required annual production of 1.8 million tons of ore could not be mined efficiently with a single pit. The multiple open-pit method is also needed to facilitate backfilling, an important first step in mined land reclamation.

Annual stripping of 6.3 million yd^3/yr of overburden (waste) is done primarily with:

1. A UH 801 Hitachi hydraulic shovel and Terex 33-11D (85-ton) trucks. The large shovel waste material is drilled and blasted prior to removal.

2. A mixed fleet of Cat and Terex 24-yd^3 scrapers and push dozers

3. A Cat 992 C loader and 85-ton trucks

4. Cat 245 mining shovels and Cat 769 trucks that remove waste interbedded with or immediately overlying the ore section

5. Small loaders and 35-ton trucks used as standby stripping units

Stripping costs are impacted by such factors as distance of haul, depth of the pit, condition of haul roads, blasted or unblasted material, density of overburden, operator skills, mechanical condition of equipment, weather, and visibility.

Because our haul roads and equipment are well-maintained and our operators are highly skilled, the major impacts on our costs are haul

distances and adverse haulage grades. Only 1983 direct costs are used in our calculations and include operating labor, lost-time labor, repair labor, service labor, operating supplies, repair supplies, and tire supplies.

Stripping production rates for a Gay Mine pit currently in production has been computer-developed to simulate comparative direct costs/yd^3 using various fleets. These costs have been further refined to show the difference between removing the top and bottom waste from this 350-ft deep pit. One-way distance of haul for top slice is 3,225 ft; bottom slide distance is 4,075 ft.

	Prod. rate Yd^3/h	Top slice cost/yd^3	Bottom slice cost/yd^3
Fleet 1- Hitachi 802 and support	650	$0.392	$0.415
Fleet 2- Scrapers and support	656	.788	.906
Fleet 3- Cat 992C and support	800	.426	.450
Fleet 4- Cat 245 and support	290	.995	1.072

In an effort to show the cost effect of increasing haul distance as the waste dump enlarges, we have added 1,000-ft and 2,000-ft level haul distances to each fleet. Increased costs for these distances are $0.01/yd^3 to $0.12/yd^3, dependent upon the fleet used.

RESEARCH NEEDS

Keith E. Evans, Assistant Station Director
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Phoshate mining in Idaho began in 1909 at the Waterloo Mine and is expected to continue throughout southeastern Idaho for several more decades. The phosphate ore is from sediments that were deposited in a Permian Sea 225 to 289 million years ago. Southeastern Idaho contains approximately 35 of the Nation's phosphate reserves. Much of this reserve is close enough to the surface to be strip-mined.

Workers and equipment have followed the mining operations to reshape and restore the mining spoils. The stabilization of mine spoils has been primarily by revegetation with grasses, forbs, and shrubs. Revegetation technology has been successfully demonstrated by the mining industry. However, concerns about the stability and hydrology of mined lands persist.

Participants of this workshop were assigned to one of the four work groups to identify research needs:

1. Coordination of mineral development with surface resource management
2. Mine plans
3. Risk analysis
4. Mined land stabilization and costs

In compiling the results from these work groups, I have highlighted the critical research needs they identified, then have listed the other research needs and other subjects discussed by each group.

GROUP 1.--Coordination of mineral development with surface resource management

Critical Needs: There is insufficient knowledge about the potential of movement of fill material in relation to:

- -Water retention characteristics of various waste materials
- -Long-term hydrologic effects of roads and other transportation facilities
- -Longevity of french drain usefulness
- -Subsidence and slump characteristics of various materials and topographic shapes
- -Options for design and placement of materials

Other Research Needs:

- -Effects of earthquakes on large fills
- -Angle and length of slope alternatives related to postmining uses
- -Face drainage systems
- -Effects of vegetation on dump stability
- -Economical methods of backfilling
- -Efficiency of earthmoving machinery
- -Long-term monitoring of vegetation, water and other resources
- -Postmining use of waste embankments, roads, powerline corridors, and other facilities
- -Optimum mine abandonment procedures
- -Defining Federal expertise needed in lease administration

Other Items Discussed by the Work Group:

- -Long-term monitoring of succession
- -Optimum fill slope length
- -Durability of waste materials
- -Growth medium and placement
- -Angle and length of slope alternatives related to postmining uses
- -Water retention characteristics of various waste materials
- -Toxicity and heavy metal content of drainage
- -Quantifying of mining values to the public
- -Quantifying environmental and mining values
- -Impacts on resources
- -Long-term postmining use of waste embankments, pit area, roads, and other facilities
- -Subsidence and slump characteristics of various materials

GROUP 2.--Mine plans

Critical Needs: Planning effectiveness is currently limited by insufficient knowledge in:

- -Information on slope stability and shaping
- -Continuous monitoring data from cross-valley fills
- -Computer applications to allow quick use of new information and to share information among companies and agencies.

Other Research Needs:

- -Cost effectiveness of transportation and mining methodology
- -Reclamation standards for highwalls and footwalls
- -Methodology to gather and exchange information on material handling in pits

Other Items Discussed by the Work Group:

- -Geological information
- -Stability of dip slopes
- -Foundation testing
- -Process technology for plant fertilization
- -Computer developed mine plans--optimizing recovery, software application
- -Role of the Intermountain Research Station
- -Maximizing resource recovery
- -Mining methods
- -Dump placement
- -Revegetation
- -Equipment for shaping
- -Esthetics
- -Transportation methodology--truck, train, slurry, conveyor
- -Monitoring baseline data for predicting water quality and sedimentation on proposed waste dumps
- -Monitoring water quality and sedimentation during construction, for the project's life, and after the project

GROUP 3.--Risk analysis

Critical Need: Risk analysis is inadequate because of a lack of knowledge on the effects that unique construction methods of mining waste embankments have on slope stability, hydrology, and settlement. Risk analysis research should quantify effects of possible events with information in the models on exposure, potential hazard, and probability of occurrence.

Other Research Needs:

- -Slope stability
- -Erosion
- -Floods

Discussion points of these main categories:

1. Slope stability

    a. Uncertainties

        -buried vegetation, snow, and ice
        -pore pressure
        -shear strength
        -soil properties
        -rock properties
        -construction methods
        -seismic data

    b. Research approach

        -general research
        -site specific research
        -is there a real identifiable risk?
        -determine what applicable research exists
        -knowledge gaps
        -do unique construction methods influence risk?

    c. Priority research needs

        -soil properties
        -drainage
        -buried vegetation, snow, and ice
        -seismic data

2. Erosion

    a. Fundamental processes and properties of erosion
    b. Slope length and benches
    c. Sediment entrapment

3. Floods

    a. Meteorological data
    b. Characteristics of extreme events
    c. Unique effects of artificially created structures compared to network impacts
    d. Hydrological properties of artificially created surfaces

Other Items Discussed by the Work Group:

- -Probabalistic analysis
- -Expanded data banks to define theory and process within the heads of industry, regulatory agencies, and land management agencies
- -Long-term operation and integrity of french drains--effect of end dumping, hydrologic risks, and other hazards
- -Risks of liquification and earthquakes
- -Foundation stability
- -Slags dumped on steep slopes
- -Toxic materials
- -Infiltration (phreatic and piezometric)
- -Dust
- -Wildlife migration
- -Settlement and creep
- -Long-term monitoring
- -Economic data base
- -Short event storms and historical streamflows
- -Cultural
- -Geology

GROUP 4.--Mined land stabilization and costs

Critical Needs: To optimize economic efficiency of mining, information is needed:

- Technical data base (computerized) to share with different companies and agencies
- Sediment basin design including information on off-site effects
- Long-term multiple-use criteria and goals

Other Research Needs:

- Improved engineering practice
- Economic alternative analysis
- Postrehabilitation use
- Slope design related to erosion
- Hydrology studies

Other Items Discussed by the Work Group:

- Design guidelines
- Long-term stabilization, hydrologic, and seismic monitoring
- Economic modeling systems--making reclamation affordable to industry
- Making equipment available to industry
- Making technology available
- Liability into perpetuity
- Obligations on historic dumps and highwalls (grandfathering)
- Selecting dumps for 20-year monitoring
- Grasses for primary stabilization
- Uses of strip vegetation
- Wildlife data base
- Aspen trees and other alternative vegetation types
- Fencing to limit grazing
- Range management incentives
- Below-surface hydrological information needs
- Siltation
- Tie monitoring into design plans
- Effect of snow at the construction site
- Surface erosion models including weather factors
- Fertilization/depth of soil models
- Risk of fishery degradation in Blackfoot River
- Surface slumps
- Purchased water
- Breaking uniform slopes (roads, terraces, and so forth)
- Geological reconnaissance
- Subsurface studies
- Geological structure control
- Safety
- Cost of operation
- Value of stockpiling topsoil (cost-benefit)

AGENDA

for the

WORKSHOP ON ENGINEERING AND HYDROLOGY RESEARCH NEEDS FOR PHOSPHATE MINED LANDS OF IDAHO

Sponsored by:
The Idaho Mining Association

The Idaho Falls District of the
Bureau of Land Management, USDI

The Intermountain Research Station
and the
Caribou National Forest
Forest Service, USDA

June 4-6, 1984
Littletree Inn, Pocatello, ID

Monday, June 4

Registration - Lobby of Littletree Inn
Social Hour - Hosted by the Idaho Mining Association

Tuesday, June 5

Registration Continued
Welcome and Introduction
Chuck Hendricks
Forest Supervisor
Caribou National Forest

Keynote Speaker
R. Max Peterson
Chief, U.S. Forest Service
Washington, DC

Coffee Break

Panel Presentation - Coordination of Mineral Development with Surface Resource Management

Panel Moderator
Mr. Tom Roederer
Deputy Regional Forester
Ogden, UT

Reclamation Standards and Objectives
Tom Roederer

Mitigation of Long-Term Loss of Surface Resources: The Purpose of the Idaho Surface Mining Act
Stanley Hamilton
Director
Idaho Dept. of Lands
Boise, ID

Phosphate Lease Forms, Terms, and Stipulations
Gordon A. Aland
Government Affairs Supervisor
Monsanto Company
Soda Springs, ID

Tradeoff Evaluation: Accumulative Effects of Mining and Postmining Land Uses
Vaughn Francis
District Ranger
Soda Springs Ranger District
Soda Springs, ID

Lunch

Panel Presentation - Mine Plans

Panel Moderator
Barney Brunelle
Chief, Branch of Solid & Fluid Minerals
State Office
Bureau of Land Management
Boise, ID

Mine Plans: Basic Regulatory Requirements
Barney Brunelle

Computerized Mine Planning Process
Treve Hocking
Principal Mining Engineer
Dravo Corporation
Denver, CO

Phosphate Mine Waste Dump Location, Design, Construction
Ed Connors
Mining Engineer
Caribou National Forest
Pocatello, ID

Tuesday, June 5 (continued)

Transportation Systems Including LANDFORM Example for System Planning
Robert V. Kimball
Director of Mine Planning
J.R. Simplot Co.
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Break

Panel Presentation - Risk Analysis
Panel Moderator
Gene Farmer
Project Leader
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Structural Factors
Loren Anderson
Associate Dean of
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Utah State University
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Hydrological Uncertainty and Risk
Richard Hawkins
Professor of Hydrology
Utah State University
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Seismic Risk
Walter Arabasz
Associate Director
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University of Utah
Salt Lake City, UT

Risk Acceptance
Gene Farmer

Wednesday, June 6

Panel Presentation - Mine Land Stabilization and Costs

Panel Moderator
Gordon Duncan
Mining Superintendent
Monsanto Company
Soda Springs, ID

Manner of Material Placement (Methods/Costs)
Rolling Hills and Pit Backfill
Gordon Duncan

Manner of Material Placement (Methods/Costs)
Angle of Repose and Regrading
George C. Toland
Managing Partner
Dames and Moore
Salt Lake City, UT

Manner of Material Placement (Methods/Costs)
Valley Fill Dump
Jim Frost and
Donald D. Smedley
Mine Superintendents
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Waste Disposal Equipment: Usage and Costs
Wayne L. Myers
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Organization of Work Groups
Keith E. Evans
Assistant Station Director
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Each attendee will be assigned to a work group. Each work group will be assigned one of the four major panel presentation topics and will be led by the panel moderators:

Group 1 - Coordination of Mineral Development With Surface Resource Management
Tom Roederer
Group 2 - Mine Plans
Barney Brunelle
Group 3 - Risk Analysis
Gene Farmer
Group 4 - Mined Land Stabilization and Costs
Gordon Duncan

The group objective will be to discuss and identify research needs so the group leader can document and report those research needs to all workshop participants.

Work Groups

Lunch

Work Groups

Group Leaders Report of Identified Research Needs

Moderator
Keith E. Evans

Wrap-up and Summary

Were Objectives of Workshop Met?
Opportunities for Continued Cooperation.
Where Do We Go From Here?
Jack G. Peterson
Executive Director
and Chief Economist
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Evans, Keith E., tech. coord. Proceedings--workshop on engineering and hydrology research needs for phosphate mined lands of Idaho; 1984 June 5-6; Pocatello, ID. General Technical Report INT-192. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 36 p.

Surface mining for phosphate in southeastern Idaho will continue for several decades. The emergent revegetation technology has been successfully demonstrated by the mining industry in large-scale applications. However, concerns about the stability and hydrology of mined lands persist. The objective of this workshop was to review current information and techniques and evaluate research needs in engineering and hydrology. Contributors came from industry, land management, and research.

KEYWORDS: mined land, phosphate, reclamation, hydrology, engineering, research needs

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The Intermountain Research Station, headquartered in Ogden, Utah, is one of eight Forest Service Research stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station's primary area includes Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Several Station research units work in additional western States, or have missions that are national in scope.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

United States
Department of
Agriculture

Forest Service

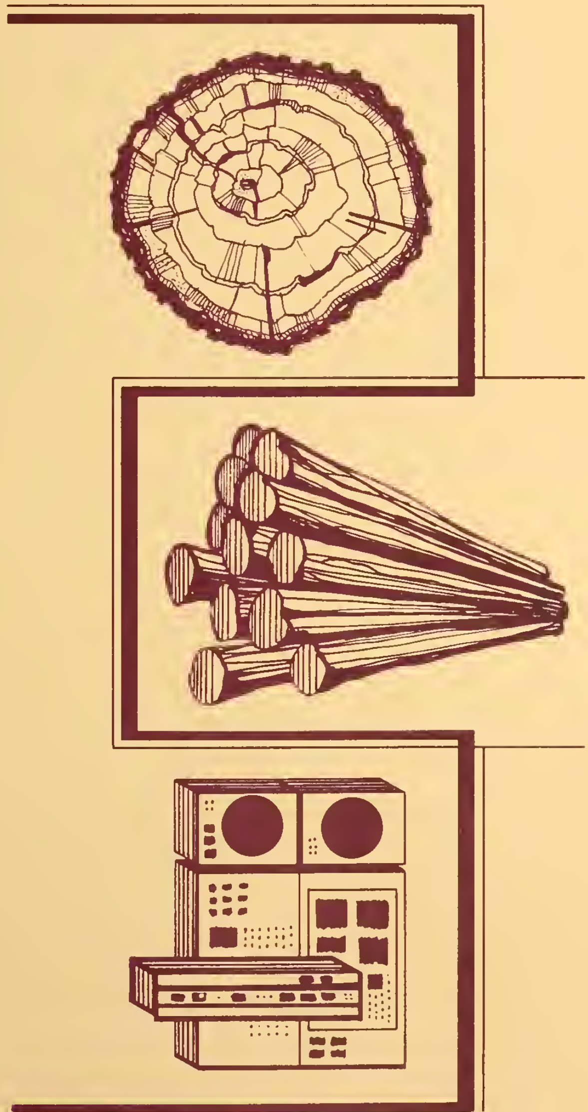
**Intermountain
Research Station
Ogden, UT 84401**

General Technical
Report INT-193

September 1985

Proceedings—Growth and Yield and Other Mensurational Tricks: A Regional Technical Conference

Logan, Utah, November 6-7, 1984



FOREWORD

This conference was designed to explore current advances in measuring and computing growth, to examine certain modeling systems for determining yield, and to discuss new as well as traditional methods for determining volume. A special attempt was made to relate these ideas to all species of forest trees. Finally, the conference was designed to provide a forum in which practicing foresters could provide comment on the adequacy of current models and methods and describe current needs.

The compilers of this proceedings are deeply grateful to those individuals who prepared and presented the papers published here, and to those individuals whose participation made the conference a success. We acknowledge Ed Harvey and Hank Cheatham, Intermountain Region, Forest Service, for their contributions as part of the program committee. We also express our appreciation to Tom Borg, Program Specialist, Utah State University, for arranging the facilities, and to Reed Christensen, chairman of the Intermountain Society of American Foresters, for supporting this event. A special thank you goes to Karen Charlton who coordinated the preparation of these papers and to Julie Davis and Liz Dailey for their fine production work.

Dwane D. Van Hooser

Nicholas Van Pelt

Proceedings—Growth and Yield and Other Mensurational Tricks: A Regional Technical Conference

Logan, Utah, November 6-7, 1984

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Conference presented by:

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Intermountain Research Station, Forest Service, U.S. Department of Agriculture

Conference sponsored by:

Inventory Working Group, Society of American Foresters

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CONTENTS

DATA FOR GROWTH AND YIELD MODELS

Robert O. Curtis and David M. Hyink

ABSTRACT: Growth and yield models have a variety of applications, and no one model can best serve all objectives for all conditions. Satisfactory models are dependent on high-quality, consistent data. Data come from some combination of inventory data and research installations. Survey or "growth trend" data provide information on growth now occurring in the present forest; while experimental or "treatment response" data provide information on response to specific treatments applied to defined stand conditions. Cost and the need for program stability and continuity make treatment response studies an activity well suited to regional cooperatives.

INTRODUCTION

Although we are not experts on sampling or inventory, we do know quite an bit about growth and yield modeling and the kind of data it takes to construct satisfactory models. So, we will confine our discussion to data to be used for the specific purpose of growth and yield modeling and, particularly, the relation of permanent plots to this objective.

GROWTH AND YIELD MODELS

"Growth and yield" is a catch-all term that can include anything from inventory updating procedures to quantitative silviculture.

A "growth and yield model" is a system that claims to provide quantitative descriptions of stand development over some range of time, condition, and treatment.

Growth and yield models can serve several purposes, including:

1. Short-term inventory projections.
2. Management planning (land classification, allowable cut, etc.).
3. Evaluation of silvicultural alternatives.
4. Generalized stand management guides.
5. Individual stand management.
6. Quantitative description of growth processes.

Paper presented at: Growth and Yield and Other Mensurational Tricks: A Regional Technical Conference, Logan, UT, November 6-7, 1984.

Robert O. Curtis is Principal Mensurationist, Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, Olympia, WA; David M. Hyink is Biometrician, Weyerhaeuser Company, Tacoma, WA.

Applications differ in required level of detail, flexibility, accuracy, and local specificity. Short-term inventory projections may assume future growth similar to past growth, but long-term estimates must take into account change in condition of the forest and future effects of practices now being applied or anticipated. To evaluate alternatives, we need estimates of results of various possible management regimes. Stand-specific estimates are needed to guide treatment of individual stands. Modeling of growth processes requires extensive biological knowledge in addition to mensurational skill.

Models differ in structure and application. Forests differ in biological characteristics, economic situation, and foreseeable management intensity. People differ in their interests and their view of the future, and they approach growth and yield with different objectives and different viewpoints, shaped by their own background and concerns. It is not surprising, therefore, that we do not have universal agreement on the best type of model, the data needed to construct it, or how best to go about the tasks of data assembly and model construction. There is no reason to suppose that the model and procedures best for one particular set of conditions and objectives will be best for other conditions and uses.

Present models can be crudely divided into two classes: (1) stand models, which use stand average values, and (2) individual tree models, which project individual trees and sum the resulting individual tree estimates to get stand values.

Stand models have the advantages of simplicity and low computing costs, but do not work well for complicated species mixtures and irregular stands. They are most popular in regions where even-aged single species stands are important. Individual tree models are more complex, but can be applied to irregular and mixed-species stands and are favored in regions where this is the predominant condition.

Models, and the computer systems which make them possible, are actively evolving. New questions and new complications are introduced by genetics, wood quality, nutritional and pest management considerations, and other factors. Development of growth and yield systems will be a continuing activity for the foreseeable future.

DATA SOURCES

Models must be based on a combination of biological principles and empirical data. When asked for immediate answers, modelers must make do with whatever data now exist. Unfortunately, models and modelers often seem more plentiful than good data, and good data are critical to satisfactory growth and yield estimates. The basic prerequisite for progress is a data base continuously improving in distribution, quality, and consistency. This must include both inventory data (which describe the existing operational forest) and research data (which describe response to treatment).

Inventories

Forestry organizations conduct periodic inventories to determine volumes and growth rates by administrative units and land condition classes. These inventories generate huge masses of data and at first glance seem the obvious basis for growth models.

Inventories have generally been oriented to estimating present volumes and values, rather than to estimating growth rates and collecting data for modeling purposes. Designs and procedures that provide satisfactory estimates of class means at minimum cost may be quite unsatisfactory as bases for growth and yield models.

The primary relationships in growth and yield models are regressions that estimate rate of change of stand or tree attributes as functions of measured attributes of the present stand (or tree and surrounding stand), including any treatment applied. One seeks estimates of regression coefficients, not class means. This objective requires that conditions influencing growth of the tree or plot be defined as precisely as possible, information that is lacking in most inventories. Small plots subject to large edge effects, ages categorized by broad classes, sketchy height samples, and inaccurate height measurements simply are not good enough. Omission of small trees, common practice in many inventories, produces unacceptable wobbles in growth curves and unpredictable ingrowth.

An inventory designed primarily to estimate present volume and value would concentrate sampling in the old, high-volume stands. Recent inventories with more general objectives often use a systematic grid. But, if we wish to model the forest of the future, we need information on the younger stands and those conditions likely to be important in the new forest. If we wish to compare alternatives, we need to sample different possible stand treatments and regimes. The conditions of greatest interest for future management are usually present in only a small fraction of the existing forest and poorly represented in inventories, or may not be present at all.

Research Studies

Because of the shortcomings of inventory data, much growth and yield modeling has used data collected outside the framework of management inventories. Data have sometimes been collected specifically for modeling purposes; perhaps more often, data have come from installations originally established for related purposes such as thinning and fertilization studies.

PLOT TYPES

Plots (whether fixed area or variable radius) ca be classified into three types based on method c growth estimation: (1) single measurement ("temporary"); (2) single measurement with retrospective growth measurements; and (3) remeasured ("permanent").

Single-Measurement Plots

These are one-time measurements of existing conditions, with no direct estimate of growth rate or mortality. The classic example of their use is the normal yield table procedure popular in the 1930's. Such data have very limited usefulness today.

Single-Measurement Plots with Retrospective Growth Measurements

Past growth of surviving trees on plots can be estimated from borings and stem analyses and converted to area estimates using the present stand table. This procedure provides quick growth estimates. It is often used in inventories and can substitute for or supplement remeasured plot procedures. Its principal disadvantages are:

1. Does not give reliable mortality information.
2. Height growth estimates are difficult an expensive (often requiring stem analyses).
3. Past treatment information is usually sketchy or lacking.
4. Does not allow controlled studies of specified treatments.

Despite these weaknesses, the procedure is ofte useful.

Remeasured ("Permanent") Plots

"Permanent" plots are established at the start an investigation and then remeasured periodically. An experimental installation may include control plots plus any desired stand treatments all at the same location.

Such plots are our main source of information o stand response to treatment. They can provide complete history of stand development and stand treatment, response to treatment, actual damage and mortality. Development of individual stand and trees can be followed over extended periods

of time and compared with predictions. And the on-the-ground examples and record of treatment and response which they provide are more convincing than any amount of elaborate statistical analysis and model-building. Permanent plots are also expensive, slow to produce results, and require stability and continuity in the research organization.

SAMPLE SELECTION

The first step in sampling is to define the population. In inventories, the population consists of all existing stands, and the primary objective is usually estimation of stratum means.

Things are less straightforward in growth and yield and silvicultural studies, where one seeks information about some largely hypothetical population of possible future managed stands. Here, the primary objective is usually estimation of regression coefficients rather than means.

Yield studies often use regression analyses of unreplicated plots established in portions of the existing forest that meet stated specifications of condition, treatment, and uniformity. Plot location within suitable areas has often been subjective, although an alternative and statistically preferable method is to select and delineate suitable stands and then locate the plot(s) within these by some random or systematic procedure. Deliberate selection of stands to obtain as wide a distribution of selected predictor variables as possible, consistent with objectives and expected application of the model, will provide better estimates of regression coefficients and better predictions near the margins of the data.

In silvicultural experiments, treatments are usually replicated at a given location according to some experimental design. Often, the primary purpose is to test some hypothesis or to define a specific relationship, such as response to fertilizer dosage or density level. Stringent requirements on initial uniformity and comparability of plots within the installation are necessary to minimize the experimental error. This generally requires subjective location of plots, with random assignment of treatments.

Most people recognize that a range of sites, stand conditions, and treatments must be sampled if conclusions from either yield studies or silvicultural experiments are to be generally applicable. It is less generally recognized that data for growth and yield modeling should also include a range over time.

Mortality is often clustered in time and space because of its association with climatic extremes and infrequent events (windstorms, insect and disease outbreaks). Growth of trees can vary widely over periods of a few years because of variation in climatic conditions, sporadic occurrence of widespread stand injuries, and cone crops. Variation with rainfall is particularly pronounced in the semiarid West. It is risky to base estimates of expected growth on measurements made in a single short, and possibly atypical, time period. Short-term variations tend to average out when data represent a series of time periods rather than a single short period. This is one of the advantages of long-term permanent plot observations and accumulation of compatible data over a period of time.

Growth Trend and Treatment Response

It is useful to distinguish two broad classes of data, which we will refer to here as (1) "growth trend" or survey information, and (2) "treatment response" information.

"Growth trend" refers to information on growth now occurring in the existing operational forest under the current type of management. This information comes from inventories or from growth plots that sample existing conditions in the operational forest. It can be used for short-term stand projections, for monitoring development of operationally treated stands, and for adjustment of regional growth models for local use. It can also be used to develop growth and yield models, although it has pronounced limitations. The only conditions sampled are those now existing in the operational forest, and treatment effects are confounded with location. Therefore, such data generally cannot provide quantitative estimates of response to specific treatments. Causal interpretations of regression relationships are uncertain, and one can have little confidence in extrapolations to possible regimes and future conditions different from those which produced the present forest.

"Treatment response" refers to the change in growth which results from a specific treatment applied to a defined stand condition. Good estimates of treatment response are essential to any model that claims to provide quantitative comparisons of the results of possible alternative treatments and management regimes.

To define functional form of relationships, estimate regression coefficients, and identify causal relationships, we need controlled experiments installed for the purpose. These must generally include treatments not now in general use and be designed to produce some stand conditions not now present in the operational forest. As one well-known statistician put it: "To find out what happens to a system when you interfere with it, you have to interfere with it" (Box 1966).

Growth and yield modeling generally involves some combination of inventory and experimental data (Stage 1977). We cannot rely solely on designed experiments, if only because these are and always will be inadequate in number and distribution, particularly for secondary species and mixed stands. But they do provide the best basis for establishing the form of relationships and they are essential for estimating treatment

effects and for predicting conditions and treatment regimes radically different from those present in the existing forest.

Designed experiments have limitations and weaknesses of their own, aside from time and cost. Although they provide reasonable estimates of suppression mortality, they do not provide satisfactory estimates of irregular, pest-induced, or catastrophic mortality. This is true both because of the erratic and clustered distribution of the latter, and because installations must usually be located in stands consciously selected for relative uniformity and freedom from major damage. Such restrictions are necessary if one is to detect treatment effects over background noise; but they also mean that observed growth rates are likely to be somewhat higher than those actually attainable in operational application of similar treatments--the so-called "falldown" effect (Bruce 1977).

This effect is not the only source of bias in models. Incorrectly formulated model components will introduce bias. But even correct formulation and good data do not guarantee unbiased estimates. Somewhere along the line, most of us learned that error in the independent variables biases estimates of regression coefficients. These biased coefficients will still produce unbiased estimates of the dependent variable, if the predictor variables contain errors similar to those in the data used to estimate the coefficients (Draper and Smith 1981).

But growth and yield models are not simple regressions. They are systems of equations in which one regression estimate (which contains error) is used as input to other regression estimates. Estimates are likely to contain unforeseen biases, and it is hard to foresee the net effect. The more accurate our measurements of the basic variables and the better the fit of the component regressions, the smaller these biases are likely to be.

Growth trend data for selected stand categories, obtained from a suitable continuous forest inventory system or randomly or systematically located supplemental growth monitoring plots, are a possible means of identifying and adjusting for such biases. Using growth trend data for stand categories of major interest, it should be possible to compare observed growth with model estimates and arrive at suitable adjustment factors. For such calibration to be feasible, measurement standards must be consistent with those used in treatment response studies.

THE PLACE OF PERMANENT PLOT STUDIES

By now it is probably obvious that we are strong believers in permanent plot studies.

In types such as coast Douglas-fir and the southern pines, thousands of permanent plots have been established over the years. Yet, many people in both the Pacific Northwest and the South see an urgent need for more permanent plot studies. Why?

Sheer quantity means little. Many of these thousands of permanent plot measurements are of very limited value. In part this is due to poor design, poor quality control in field and office, and procedural inconsistencies that make it difficult or impossible to combine data into a common analysis. Only a small proportion of these data apply to those conditions and questions of most importance in evaluating alternatives for the future forest. On the other hand, there are numbers of well-conceived, well-designed, and well-executed permanent plot studies which have been and are invaluable.

Many administrators dislike permanent plot studies. They often fail to grasp the continuing value of well-designed and well-executed studies, but they see clearly the costs and continuing commitment of resources. Conversely, researchers often become attached to their old studies. It is frequently hard to persuade them to junk marginal studies that represent conditions of very limited interest in the future and that were often poorly designed to begin with.

We give here some opinions based on recent discussions among a number of organizations in the coastal Pacific Northwest (University of Washington 1984).

1. In general, new permanent-plot growth and yield installations should be established only a part of a carefully planned series designed to give reasonable coverage of some defined range o site, geography, stand conditions and treatments
2. Plot procedures and records must be standardized to ensure compatibility of data among installations. Consistency and tight quality control in field and office are absolutely essential.
3. The primary objective should be to produc data suitable for defining response surfaces. Therefore, studies should probably involve minimal replication at each location, but many locations.
4. Each installation should include a basic set of standard treatments common to all locations, while allowing optional additions to this basic set.
5. The basic design should:
    a. Use relatively large plots, which can (1) be continued over a long period of time, (2) provide good diameter distribution data, (3) provide opportunity for subsequent thinning and other stand treatment, and (4) be considered representative of conditions operationally attainable.
    b. Be relatively simple and undemanding in requirements for suitable areas.
    c. Be planned primarily for future poole analyses, across installations.
6. Effort devoted to species, types, and geographic areas should be related to their long-term importance (acreage and productivity).

7. No one organization can establish and maintain an adequate system of such installations. Cost, and the need for program stability and continuity, make this an activity best suited to regional cooperatives.

SUMMARY

1. There is not and is not likely to be any one growth and yield model that is best for all situations and all applications.
2. Development of growth and yield systems will be a continuing activity for the foreseeable future.
3. Satisfactory growth and yield models are dependent on availability of high-quality data for a wide range of stand conditions and treatments.
4. Data from past conventional inventories have not generally proven suitable for growth and yield modeling.
5. Both survey data and "treatment response" data from designed experiments are needed.
6. Treatment response studies provide the best basis for establishing the form of relationships and are essential for estimation of treatment effects and predictions for conditions and treatments radically different from those present in the existing operational forest. There is a continuing need for such permanent plot studies.
7. New permanent plot studies should generally be established only as part of a carefully planned program. They should be designed with the primary objective of defining response surfaces. Because of costs and the need for stability and continuity, such programs are an activity best suited to regional cooperatives.

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SAMPLING FOR GROWTH ON INDUSTRY LANDS:

OLD-GROWTH VERSUS SECOND-GROWTH CONSIDERATIONS

Steven Kleinschmidt

ABSTRACT: As the forest resource changes, so do needs for growth information. Present needs reflect the transition from the management of existing stands to the management of potential stands. Harvest plans in old-growth forest depended entirely on maintaining a controlled forest inventory of a static resource. Second-growth planning must focus on a dynamic resource and depends on accurate, site-specific stand tables. Old-growth volume estimations do not provide the data necessary for future growth estimation, as do permanent plots stratified by expected future forest characteristics. The factors that define future stand production are site productivity and stand development class. Although this approach is not new, the challenge to foresters is to make it operational.

INTRODUCTION

The emphasis in industrial forest management has been inexorably moving toward second-growth management. Companies either have little old-growth timber remaining or recognize that our survival inevitably depends upon effective management of second-growth.

In response to a changing management and planning environment, a viable inventory system must anticipate and support expanding information needs. Growth data have been regularly collected in industry's controlled forest inventories, but why do we need growth information? Simply, as with all inventory data collection, to provide information for managers to make better decisions. Top management uses this information to project a view of the future forest and the opportunities that this future forest can provide to produce profit. Land managers use similar information to implement the forest objectives on a unit-by-unit basis.

As the resource has shifted from old growth to second growth, the forest objectives and management styles have also changed. For our inventories to be effective in sampling for growth, there must first be an assessment of what growth information is needed and how it will be used by land managers and planners.

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STAND MANAGEMENT

Industrial stand management in the Northern Rock Mountains is in various stages of evolution from old-growth to residual old-growth to second-grow. This is more than a change from managing old, bi trees to young, small trees. The transition involves adopting the philosophy of a timber farmer whose management activities can entirely shape the character of the future crop. It is a primary change from management of the existing standing volume to management of the potential, future volumes (fig. 1).

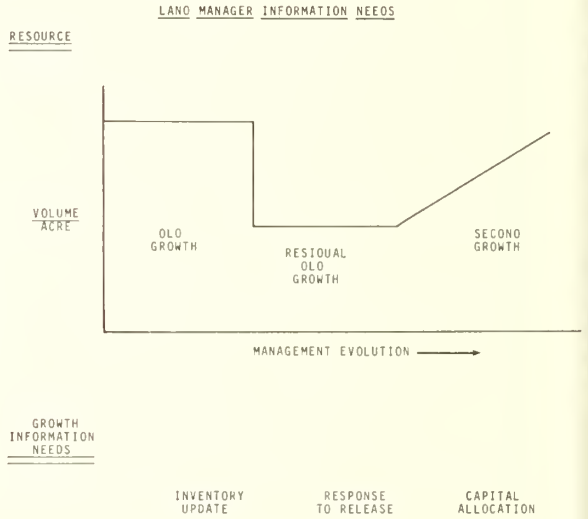

Figure 1.--The land manager's requirements for growth information are changing in response to a changing resource.

Old-growth stands are usually high-volume stands that have had little or no management entries. The resource being managed is the standing volum and the primary need for growth information is for inventory update to carry the volume forward until the next cyclical inventory. Growth rates are usually low, particularly when increment is compared to the standing volume.

In the Northern Rockies, residual old-growth stands are a mixture of old-growth remnants and submerchantable trees regenerated from the earli pine and larch sawlog harvests. There may be substantial cubic volume in these stands, though board foot volumes are often low. The growth information needs for these stands are centered the response to release as the old-growth remnan are removed. Is the understory vigorous enough

to respond, or should it be harvested or slashed and a new stand regenerated? The existing volume and stocking will have an important influence on how this question is answered, but equally important is the stand's potential production.

Second-growth are the stands that are regenerated after the removal of the old growth. They are generally classified into natural and artificial regeneration, thinned and unthinned. The management activities, planting and thinning, that occur early in the life of the stand are the primary influence that will determine future merchantable stand characteristics. The second-growth management considerations are stand establishment and the allocation of capital for intensive stand management. Where can yields be effectively increased through the management activities of planting and thinning? The growth information required for silvicultural capital allocation is potential stand production. As land managers move from an old-growth to second-growth base, the information requirements for existing stand production are being replaced by potential, future stand production. The allocation of scarce capital is the critical decision component.

FOREST PLANNING

Forest management planning has also adapted to the changing character of the forest as we move from a static to a dynamic resource. The development of harvest plans in an old-growth forest depended entirely upon maintaining a controlled forest inventory (fig. 2). The planning needs were effectively served by relatively simple tools such as growth percentages for inventory update-projection and volume regulation formulas for allowable cut calculations. These tools proved useful for old-growth planning because they adequately reflected the overriding importance in stand valuation of the existing volume inventory and the high-valued product revenues.

OLD GROWTH PLANNING SYSTEM

INVENTORY PROJECTION - GROWTH PERCENT

$$V_{t+1} = V_t + GP\ (V_t)$$

ALLOWABLE CUT - VOLUME REGULATION

HANZLIK

$$\text{ANNUAL CUT} = \frac{\text{VOL. OVERMATURE}}{\text{ROTATION}} + \text{INCREMENT}$$

KEMP

$$\text{ANNUAL CUT} = \frac{A_R + 3A_{ss} + 5A_p + 7A_{sw}}{4\ (\text{ROTATION})} + V_{sw}$$

Figure 2.--An example of an old-growth planning system using growth percentages and volume regulation formulas to plan harvests for a high-valued resource.

In second growth the shorter rotation, smaller, more consistent wood determines that stand valuation will no longer be dominated by product revenues, but by operational costs and merchantability specifications. A small change in merchandising specifications can drastically affect the merchantable volume per acre and as a result, impact the per unit costs and wood flows. Examinations of alternative merchantability and cost scenarios in second-growth harvest planning cannot be accomplished with estimates of total strata volume and average costs per unit, but require a linkage between accurate, site-specific stand tables and cost information.

Long-range planning in a second-growth environment requires an increasingly complex forest mosaic of stand development classes. While timber type (species-size class) strata were appropriate in old-growth planning; stand development classes typified by species, size class, site productivity and management activity become crucial to the projection of future inventories. Again, management intervention and potential productivity define second-growth strata. As land managers use potential productivity to define strata for silvicultural capital allocation, planners must also stratify their forest by not only existing conditions, but by anticipated future conditions and the response to these management interventions.

Industrial forest planners have relied on system analysis techniques such as linear programming, dynamic programming, simulation, and network analysis to provide both the flexibility in evaluating alternative cost and merchantability assumptions and the ability to handle large numbers of strata for long-term wood flows (fig. 3).

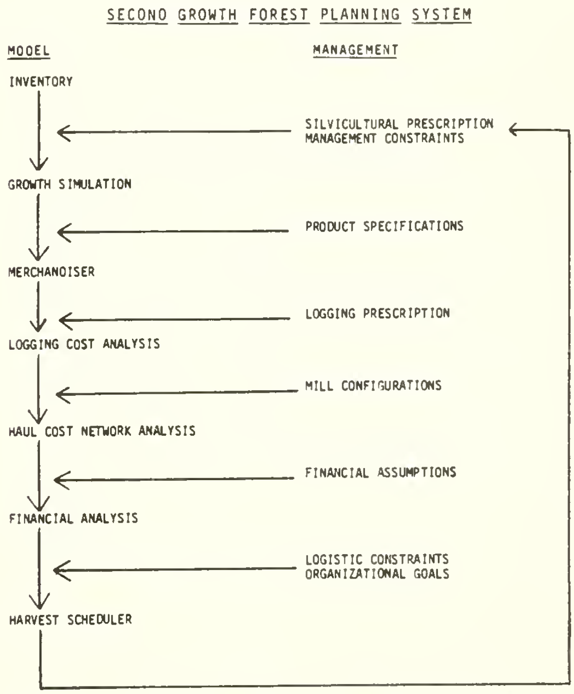

Figure 3.--An example of a second-growth planning system using system analysis to plan harvests for a cost-sensitive resource.

This type of planning model provides a framework for foresters to evaluate the implications of their multiple management and economic assumptions. Moreover, for effective planning, these data-intensive models require future productivity estimates for projecting a large number of diverse stand development classes and refined stand tables for the harvesting of near-term stands. Though outwardly more complex than the old-growth models, the style and structure only reflect the shift from a static, high-volume, high-valued resource to a dynamic, variable-volume, cost-sensitive resource.

INVENTORIES

Management and planning styles are evolving in response to this changing resource and, as a result, the needs for inventory and growth information are also changing. Inventory design must anticipate this evolution if it is to provide useful, timely, management-oriented information.

Old-growth inventory designs have concentrated on the need for estimating total volume. Continuous Forest Inventory (CFI) plots and cyclical temporary plot inventories have traditionally been used to estimate volume. Usually the forest is stratified by timber type, and plots are concentrated in the high-volume strata. The sampling for growth is piggy-backed on this volume estimation sampling design. With an existing, stable, old-growth resource, this strategy provides the information required for inventory updates and planning future harvests.

In second growth, increment is not a secondary information component that can be simply overlayed upon a volume-oriented sample design (fig. 4).

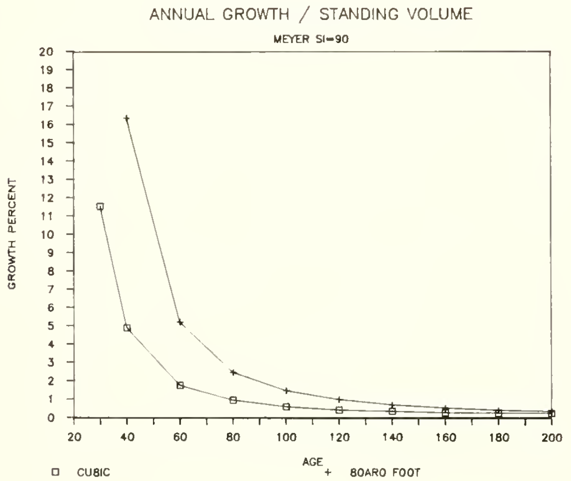

Figure 4.--Annual growth as a percent of standing volume for site index 90 ponderosa pine (Meyer 1938) over a range of stand ages. Growth is a more important stand parameter for shorter rotation, second-growth stands than in old-growth stands.

Growth estimation becomes a more important forest parameter when the large standing volumes are not present, providing an overriding influence on management decisions. When managing the shorter (under 100 years) rotation of second growth, annual increment quickly becomes the dominating influence for projecting future volumes.

The collection of past growth information is of less value in second growth than in the old-growth inventories due to the younger age classes and management intervention. The growth measured from volume inventory plots provides a snapshot of where a stand has been but not where it is going. With rapidly changing growth rates in stands less than 100 years old, extrapolation of past growth could easily underestimate future production, resulting in foregone capital investment opportunities or overestimate, resulting in excessive future wood supply projections (fig. 5). In addition, pretreatment growth rates will hopefully have little correlation with posttreatment response to density control. While growth is a minor and consistent component in old-growth projections, it is a primary but variable component for second-growth projection. By necessity, the standing volume estimation should be divorced from the future growth estimation.

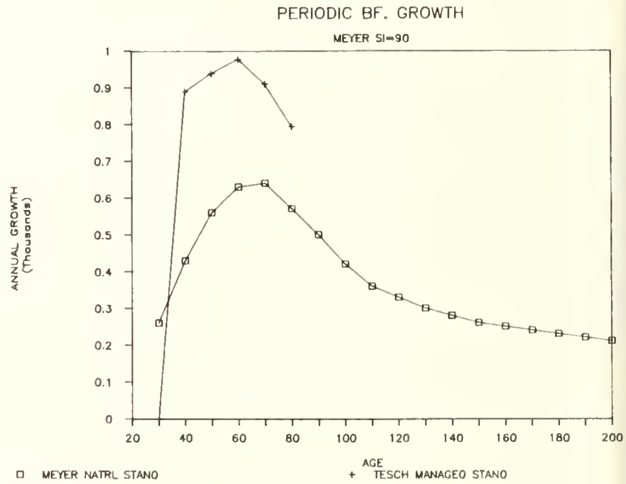

Figure 5.--Periodic board foot growth over a range of stand ages for a natural stand (Meyer 1938) and a managed stand (Tesch 1980). Growth rates are rapidly changing and less predictable for second-growth stands due to shorter rotation and a range of management activities.

Caught in the middle between demands for site-specific stand tables and the need for alternative sampling approaches for future growth estimation is the inventory forester with a fixed budget. It is possible to meet these increasing information demands, but only if sampling strategies are targeted specifically toward collecting only the pertinent information required for that phase of the inventory.

The conventional inventory must concentrate on the information needs from the existing stand, such as stand tables and management objectives and constraints. These data can be collected within a design using a mixture of volume point sample plots and fixed radius regeneration plots. To efficiently achieve the increased sample intensity inherent to site-specific inventories, the management unit inventory should concentrate on the estimation of site productivity and stand development class. Site productivity can be estimated from measured site trees or site characteristics such as slope, aspect, habitat type, and soil type. Stand development class can be defined by stand structure and management strategy. By limiting the management unit inventory to a basic cruise, considerable efficiency can be gained in order to keep a site-specific inventory of second growth up to date. Growth can be measured on these plots for an index of vigor, but only a subsample would be needed. Alternative measures such as crown ratio provide vigor information and can be collected more quickly.

GROWTH INVENTORY

Primary increment information for second-growth stands should be sampled using a design that provides future growth information. A viable approach to this problem is a permanent plot system stratified by expected future forest characteristics.

Permanent plots are irreplaceable for second-growth information needs as long-term response to silvicultural treatments can be tracked. Crucial components of growth, such as height growth and mortality, can only be reasonably monitored on permanent plots. Old-growth could be efficiently managed with the assumption of little to no height growth, but the capability of a stand to reach merchandising specifications at 16 or 32 feet will be vital in the development of a management plan. Mortality, always the bugaboo for mensurationists, can readily be measured and evaluated for causal factors on permanent plots.

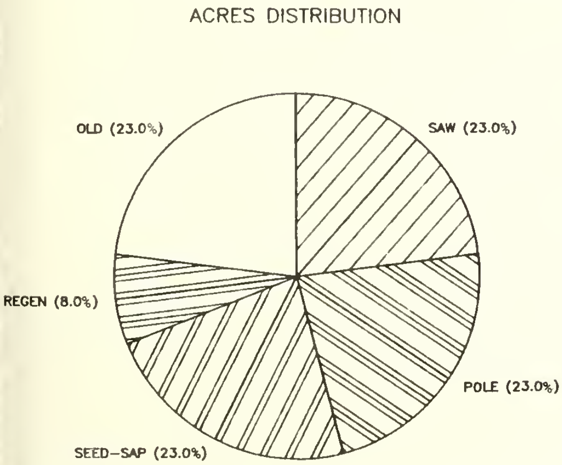

Figure 6.--A representation of a hypothetical forest managed under acreage control.

Stratification in sampling growth should be oriented toward providing information on future, potential production. Therefore, the forest should be stratified not by existing stand conditions, but by future stand conditions and future production. For a hypothetical forest with acres equally distributed over size classes (fig. 6), alternative views of the forest are presented for volume and growth estimation (fig. 7). By evaluating the resource using future stand conditions and production, you will arrive at an entirely different view of your forest and an entirely different sampling strategy from that of the volume inventory. Greater emphasis is placed upon stands that are entering the higher productivity classes. Pole and seedling-sapling stands, thinned, and planted stands will have a greater weighting due to their higher production.

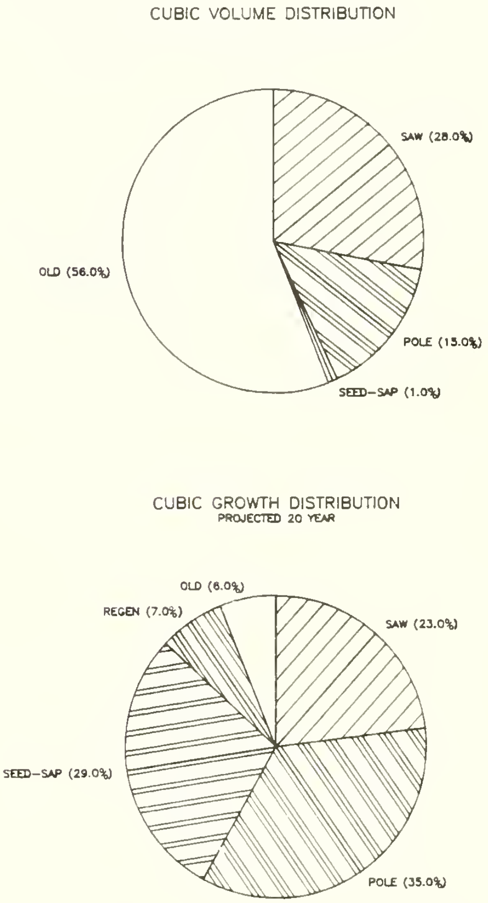

Figure 7.--Alternative views of the same forest depending upon whether cubic volume or cubic growth is the forest parameter to be sampled.

The factors, previously identified, that define future stand production are site productivity and stand development class. Stand development classes have been referred to throughout to stratify inventory and growth populations for the second-growth forests. This classification provides the flexibility to consider existing stand conditions and also include expected future development. In industrial forestry, silvicultural intervention leaves a significant imprint on the

future forest and must be included in any stratification; however, each organization must assess the factors that will determine the characteristics of its own future resource.

The evaluation of future stand conditions, though difficult, can be a creative management assessment of the direction that the forest is headed. This implies that the stratification does not remain static with the initial growth plot establishment but must be periodically assessed. This type of assessment can only be healthy for an organization.

To apply the information from the growth inventory system, continuous managed stand growth and yield tables can be produced using either conventional empirical yield summaries or computer-based variable density yield table generators. The periodic remeasurement and establishment of plots in new strata provide an ongoing, continuous data base for growth and yield table recalibration. To estimate existing and potential forest production, the inventory cruises supply the site and stand development classifications for entry into the growth and yield tables.

Proposing to measure growth on permanent plots stratified by conditions that will exist in the future forest is nothing new. Research foresters have consistently used this approach. The challenge is to take this research approach and make it operational. Nearly all forest management companies in the Northern Rockies use local growth and yield information to project future stands for management and planning purposes. The continual recalibration of local growth and yield tables is no longer a research activity, but is an ongoing activity for a forward-looking, operational inventory.

The sampling strategy for estimating increment in industrial second-growth forests may not be readily applicable to all organizations; however certain common factors exist in developing a sampling strategy. For information to be useful and timely, it is imperative that form follows function. This requires an inventory design based on a thorough assessment of the resource and an evaluation of the present and projected user information needs. Against a clearly defined picture of management information needs, alternative sampling systems can be evaluated for efficiency, timeliness of information delivery, and level of detail for today's and tomorrow's inventory.

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CALCULATING GROWTH FROM VARIABLE PLOTS:

ARE WE FITTING SQUARE PEGS INTO ROUND HOLES?

Charles J. Chambers, Jr.

ABSTRACT: Good documentation of the theory, development, and use of variable plot sampling dates back to 1952. Many foresters look upon the growth components of fixed plots as different than those of variable plots. In fact, they are not. Ongrowth trees, "the square peg," are handled differently in two common methods of variable plot growth calculations. Both are correct, but both sometimes produce confusing results. In the "Bitterlich method," growth equals measurement 2 minus measurement 1, but very erratic growth estimates occur (high variance); the "Beers method" causes a more realistic growth estimate, but growth is not equal to measurement 2 minus measurement 1. Both methods will give statistically similar answers, but the Bitterlich method will vary the most. Approaches have been developed that make volume and growth estimates compatible with greatly reduced variances. The use of variable plots for growth causes no real problems that do not also show up in fixed plots.

INTRODUCTION

The concept of variable plot sampling was first reported by an Austrian forester, Dr. Walter Bitterlich, in 1948. About 5 years later, Grosenbaugh (1952) introduced the concept in the United States; he extended it to the estimation of volume, number of trees, and so on, and developed a sound theoretical basis for it. Many universities and agencies conducted research to refine and develop the theoretical and practical aspects of the system, but it took about 10 to 15 years before the American forester began to appreciate the new system and use it in estimating timber volumes.

The theory, development, and use of variable plot sampling has been well documented in publications that date back to 1952. I assume that most of you are familiar enough with variable plots to permit us to move right into the main subject of growth using variable plots. For a review or a first exposure, I recommend Grosenbaugh (1958), Bruce (1961), Beers and Miller (1964), and Husch and others (1972). Literature bibliographies are available from Thompson and Deitschman (1959) and La Bau (1967).

Although foresters now use the variable plot system for timber inventory and cruising, many have hesitated to use it for permanent plots for research or CFI uses. The idea of using a variable plot system for growth estimations resembled making square pegs fit into round holes in that the system seemed totally inappropriate for obtaining the desired data. This paper will focus on making the reader see that, in fact, the "square" peg always was round. The important point is that "variable plots" means that they vary in size when established, not that they vary over time. In support of using a variable plot system for growth estimates, I will conclude with a brief review of how the Washington State Department of Natural Resources has used a variable plot system for growth and yield information.

GROWTH COMPONENTS

Many foresters look upon the growth components of fixed plots as different than those of variable plots. In fact, they are not. Growth components of both are:

1. Survivor trees (trees that were measured in period 1 and then remeasured in period 2)
2. Cut and mortality trees
3. Ingrowth trees
4. Ongrowth (the square peg)

Calculating the growth of survivor trees for fixed plots and variable plots is straightforward and can be handled similarly. The problems of handling ingrowth trees are also the same for fixed and variable plots. Ingrowth is defined as trees not previously large enough to be included by the inventory specifications and which "suddenly appear" on the fixed plot or variable plot once they are of merchantable size. In the variable plot system, each tree represents the same basal area as any other tree, regardless of size. Consequently, the effect of ingrowth is even greater when it does occur, although it occurs less frequently on variable plots. This form of sudden change is generally tolerated in both sampling systems. (Iles and Beers 1983). The most promising current tactic in Iles' opinion (1981) is to establish a sufficiently large minimum plot size for small trees.

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The Washington State Department of Natural Resources has included all trees 1.5 inches and larger to reduce, but not totally solve, the problem of ingrowth. The sudden loss due to mortality or harvest remains a major problem for both fixed and variable plots. It is the one problem which seems to lack a practical solution in either system at the present time (Iles 1981). The last component of growth is the "ongrowth trees," the square peg in the eyes of many that is the focus for the remainder of this paper. Briefly, ongrowth trees are those not included in the sample on the first measurement, even though of merchantable size, but that are included in a subsequent measurement. How these trees are handled in growth calculations will be discussed later, and the definition of ongrowth should be kept in mind.

PLOT SIZE CHANGES

What is happening with ongrowth trees also occurs with fixed plots when plot size changes. Let's say we have a 10-year-old Douglas-fir stand. We establish a 1/40-acre fixed plot, and a total of 10 trees are on the plot. The object of the inventory is to maintain at least 10 trees for measurements over time. As the years go on, thinning takes place and soon only five trees remain. The forester therefore doubles the size of the plot, and creates a larger plot with a new combination of trees. New estimates for the stand may be quite different than for the old 1/40-acre plot. The same thing happens each time he returns to his variable plot if he checks for ongrowth trees with his prism; basically he changes the size of the plot and creates a new combination of trees. This problem thus shows up in both systems.

Traditionally, fixed plots never seem to be measured long enough to require changing plot size in order to achieve plot efficiency. (Plot efficiency is defined as maintaining enough trees on a series of plots to keep the variation to a minimum. In a series of 1/40-acre plots with one tree per plot, the variation would be high. If the plots are 1/2 acre with many trees per plot, the variations would be markedly reduced. Some combination of a small variance and dollars spent must be considered in plot efficiency.) On the other hand, with variable plots inventory foresters feel they need to check for ongrowth trees at each measurement. This check is probably not necessary, and the efficiency of a variable plot could last over a number of remeasurements.

What seems to bother almost everyone dealing with growth is the typical printout of a remeasurement of a variable plot where ongrowth trees have been noted (table 1).

Table 1.--Typical basal area growth (ft^2) on variable plots with and without ongrowth trees

Plot	Measurement 1	Measurement 2	Ongrowth trees	Growth
1	40	60	Yes	7.7
2	60	60	No	6.8

CALCULATION PROBLEMS

Why does 60-40 show a growth of 7.7 ft^2 on plot 1, and 60-60 a growth of 6.8 ft^2 on plot 2? An understanding of the two ways growth can be calculated on variable plots is needed to clear up the confusion. The first of the two methods I will call the "Bitterlich" method. (This does not imply that Bitterlich advocates the method, just that it was one of the earliest attempts and therefore became associated with him.) This method calculates the growth estimate as the difference in successive estimates from one period to another. This sudden change of growth caused by the ongrowth tree makes the operational forester uneasy because of the large variance in growth. Using a five-plot example, the principle and large variances of the method are illustrated (table 2).

Table 2.--Growth calculations by the Bitterlich method

Plot	Measurement 1	Measurement 2: Survivor	Measurement 2: Ongrowth (OG)	Measurement 2: Totals
	------------Basal area per acre, ft^2------------			
1	40	40	20	60
2	60	60	0	60
3	140	140	0	140
4	110	110	10	120
5	120	120	30	150
Total	470	470	60	530

Growth = (Survivor basal area + ongrowth) - Measurement 1

60 = 530 - 470

We now recognize two conditions of the Bitterlich method:

1. Growth = measurement 2 - measurement 1, and
2. Very erratic growth estimates (high variance) per plot occur as shown in table 2. This would be the same for fixed plots if recalibration takes place (change in plot size).

To make the square peg round and get away from erratic growth, Beers (1964) and earlier Grosenbaugh (1958) introduced a system in which the estimates of basal area and basal area growth are independent of each other. Initial basal area is estimated using Bitterlich's estimator or some alternative estimator. The growth estimate is usually based on trees included in the initial measurement, and the ongrowth trees are not considered. Although Beers shows the ongrowth trees in his tables, he does not recommend they be used. In fact, ongrowth trees (which is a recalibration of plot size) should only be taken when the plots become inefficient. Forget them! Table 3 illustrates our first example (table 1, plot 1) in more detail.

Table 3.--Comparison of growth methods

Measurement 1				Measurement 2		
D.b.h. (D1)	Basal area (BA1)	Trees per Acre (T/A1)		D.b.h. (D2)	Bitterlich Basal Area (BA2)	Beers Basal Area
10	20	36.7	Survivor trees	11	20	24.2
12	20	25.5		13	20	23.5
			Ongrowth trees	14	20	--
Totals	40	72.2			60	47.7

Bitterlich Growth: BA2 - BA1 = 60 - 40 = 20 ft².

Beers Growth: (T/A1 * ($D2^2$ * 0.005454)) sum for all trees - BA1 = 47.7 - 40 = 7.7 ft².

Now we have a situation of more realistic growth estimations per plot, but:

Growth ≠ measurement 2 - measurement 1

7.7 ≠ 60 - 40

Bitterlich's method bothers some because growth is too variable. Beers' is consistent, but it bothers others because it doesn't add up.

Which of the two is better? Well, this depends on the user. Flewelling (1981) goes into more detail in his comparison of each method. (I should point out that Flewelling uses different nomenclature than I have used. He refers to the Bitterlich method as compatible and Beers' method as noncompatible.)

Looking back at table 1, the confusion comes about because the example is mixing the two methods. The user is confused because of the noncompatibility, that is, measurement 2 ≠ measurement 1 + growth.

In other words, select one method and stay with it, or show both growth estimations for each plot and total.

In summary, the Bitterlich estimate associated with the usual basal area estimator has a high variance; Beers' method with less variance is usually preferred, but both are unbiased. In other words, if "x" number of plots is analyzed, both methods give statistically similar answers, but the Bitterlich method would vary the most.

IMPROVED METHODS

Can anything be done to cause less variance in growth and measurement 2 to equal measurement 1 + growth? In other words, can the best of both worlds be reached? Two recent approaches enable us to achieve these ends. Iles (1979), Iles and Beers (1983), and Flewelling (1981) introduced methods to solve the problem of large and sudden changes. They modify "the shape of the estimate" over the plot area surrounding the tree and into which the sample plot might fall. In a nutshell, what they are saying is to only account for the shell of additional wood that is put on between measurement 1 and measurement 2 as growth. Their approaches have several advantages (Iles and Beers 1983). They are:

1. Volume and growth estimates are "compatible" with a much reduced variance (growth = measurement 2 - measurement 1).

2. Volume estimates change slowly and consistently as the plot size changes.

3. Method can be applied to plots already measured if the distance to the trees is known.

Additional discussion is available in Iles' and Flewelling's papers.

DON'T CHANGE SIZE

In conclusion, the substitution of variable plots for permanent plots causes no problems that do not show up in fixed plots. They are not noticed in fixed plots because we changed the size infrequently. The solution is the same in both cases: don't change the plot size. The big advantage of variable plots over fixed plots is the cost-efficient estimates of volume or growth or both. Ingrowth trees have the same problem for both variable plots and fixed plots. A sudden loss of trees remains a problem in both. Survivor trees are handled the same. The "compatibility" question only arises when recalibration takes place. This too can be taken care of by using Iles' or Flewelling's approacnes.

In practice, the Washington State Department of Natural Resources has been using the variable plots system since 1957, when the original inventory was established. Nine years later, 3,500 variable plots were established for growth and yield. By 1980 the Division of Timber Sales started cruising using the variable plots system. Flewelling told us (1981) "of the many organizations I have contacted, you have maintained the best records and are probably making the best use of your growth data."

One use of the data was the development of a basal area growth equation which was used to derive growth tables for Douglas-fir (Pseudotsuga menziesii) (Chambers 1980) now being used in the Pacific Northwest. This procedure was later described by Clutter (1983) as an acceptable means to predict future yields using a basal area growth equation derived from variable plots. Last, but not least, we are now developing growth estimations from the department's 2,500 variable plots in eastern Washington for the allowable cut calculation.

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SQUARE PEGS AND ROUND HOLES: PROCEED ONLY WITH CAUTION

Roger C. Chapman

ABSTRACT: Estimation of stand growth from variable radius plots has been the subject of some misunderstanding among foresters. Grosenbaugh in 1958 and Beers and Miller in 1964 identified the phenomenon of "ongrowth" and suggested procedures for estimating growth from remeasured points. Several methods have been suggested for estimating growth using diameter increment cores and temporary variable plots. Using the basic probabilistic concepts of PPS sampling, it is shown that a choice of basal area is a critical element in estimating and interpreting tree and stand growth when one is using either temporary or remeasured points.

INTRODUCTION

The use of probability proportional to size (PPS) sampling to estimate stand growth often has been debated among foresters. In the subsequent paragraphs some of the probabilistic elements of PPS sampling which are associated with stand growth estimation are discussed. The focus is on the probabilistic structure of the Grosenbaugh (1958), Beers and Myers (1964) stand growth estimators and procedures. Those readers interested in the variance characteristics of stand growth estimators or ongrowth are directed to Flewelling (1981), Martin (1982), and Flewelling and Thomas (1984).

In the search for computationally efficient estimators, we often forget that the individual tree's probability of being sampled is an essential element in PPS sampling. The probabilistic aspects of PPS sampling are particularly important when variable plot data are used to estimate stand growth.

The probability that a given tree will be sampled in a 1-acre forest with a single randomly located point is

$$p = \frac{\text{area of tree's projected circle (ft}^2\text{)}}{43560}$$

$$= \frac{\text{tree basal area (ft}^2\text{)}}{\text{BAF}}$$

$$= 1/\text{STF}$$

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where STF is the stand table factor associated with the given tree and basal area factor, and BAF is the basal area factor.

The general formula for estimating the per acre value of any tree characteristic y_j--is

$$\hat{Y}_a = [1/n] \sum_i^n \sum_j^{m_i} [y_{ij}/p_{ij}]$$

or alternatively

$$\hat{Y}_a = [1/n] \sum_i^n \sum_j^{m_i} [STF_{ij}*y_{ij}]$$

where

n = the number of points sampled,

p_{ij} = the probability of the jth tree on the ith point being sampled,

STF_{ij} = the number of trees per acre represented by the jth in tree on the ith point,

m_i = the number of "in" trees at the ith point, and

Y_{ij} = the characteristic of interest on the jth tree on the ith point.

PROBABILITY, GROWTH, AND TREE SELECTION

In developing sampling techniques to accurately and precisely estimate stand growth it is necessary not only to state whether one is estimating past growth or predicting future growth but also to carefully define the type of growth (net, gross, with or without ingrowth and/or mortality), and cut that is to be estimated.

Obviously when trees are sampled proportionally to their size, the probability of a tree being sampled increases with time. In a 1-acre forest the probability of initially sampling a tree of diameter d with a single randomly located point is

$$p_1 = 0.005454\ d^2/\text{BAF}.$$

After n years and diameter increment Δ the probability of sampling the tree with a single randomly located point becomes

$$p_2 = 0.005454\ [d + \Delta]^2/\text{BAF}.$$

The relative change in the probability of selection, p_2/p_1, associated with a given diameter increment Δ is

$$p_2/p_1 = [1 + \Delta/d]^2,$$

$$= STF_1/STF_2.$$

The change in the probability of selection is not only a function of the diameter increment occurring during the period but also of the initial diameter. For a given diameter increment the relative change in the probabilities of selection, p_2/p_1, declines as diameter increases.

The changes in the probabilities of selection associated with a range of diameters and with specified diameter increments are shown in figure 1.

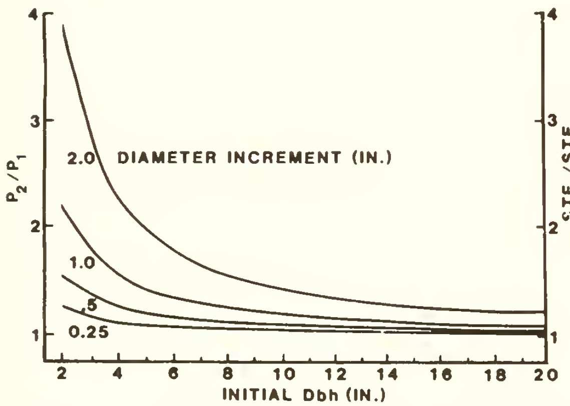

Figure 1. --Changes in probabilities of selection associated with range of diameters and specified diameter increments.

Stand growth can be estimated from remeasured plots or from temporary points if additional growth information is collected. The subsequent paragraphs describe the estimation of growth from remeasured and temporary points.

ESTIMATED GROWTH FROM REMEASURED POINTS

Grosenbaugh (1958) and Beers and Miller (1964) advocated using only trees that were "in" at the beginning of the measurement period to estimate stand growth when remeasured points were being used. In constructing growth estimators, they used the probabilities associated with the diameter when trees were first of merchantable size. For trees of merchantable size and "in" at the beginning of the measurement period, the probability p_{ij} associated with the initial diameter $d_{1_{ij}}$ was used. For trees of less than merchantable size but "in" at time of first measurement and growing into merchantable size during the remeasurement period, the probability $p_{2_{ij}}$ associated with the diameter at the end of the period, $d_{2_{ij}}$, was used. Their estimator of per acre volume growth is

$$\hat{vg}_a = 1/n \sum_i^n \sum_j^{m_i} [(1/p_{1_{ij}}) * gv_{ij}] + [(1/p_{ij}) * gv_{ij}]$$

$$= [1/n] \sum_i^n \sum_j^{m_i} [STF_{1_{ij}} * gv_{ij}] + [STF_{2_{ij}} * gv_{ij}]$$

where

$gv_{ij} = [V_{2_{ij}} - V_{1_{ij}}]$,

$V_{1_{ij}}$ = the volume at the beginning of the measurement period of the jth tree on the ith point,

$V_{2_{ij}}$ = the volume at the end of the measurement period of the jth tree on the ith point,

$p_{1_{ij}}$ = the probability of selecting the jth tree on the ith point at the beginning of the time interval, and

$STF_{1_{ij}}$ = the stand table factor of the jth tree on the ith point at the beginning of the remeasurement period.

Ongrowth trees, trees originally classified as "out" but which grew sufficiently to be "in" at time of remeasurement, are ignored in Grosenbaugh's and Beers and Miller's estimates of stand growth. Inclusion of ongrowth trees in the growth estimators not only increases the estimated growth but also usually inflates the standard errors associated with the growth estimates.

Myers and Beers (1968) compared the average annual basal area ingrowth per acre obtained from 0.2-acre plots in Wisconsin with estimates obtained from PPS sampling when (1) ongrowth trees were ignored, (2) basal area on ongrowth trees was included with ingrowth, and (3) basal area growth of ongrowth trees was included from the time they qualified for the sample. The results of their study are summarized in figure

ESTIMATING GROWTH FROM TEMPORARY POINTS

In estimating stand growth from temporary points one must decide whether one wishes to mimic the type of stand growth estimates obtained from remeasured points or to estimate the past stand growth of surviving trees.

When temporary points are used to mimic or supplement remeasured points all tallied trees should be increment bored (Grosenbaugh 1958) in order to determine the status of the tallied trees at the beginning of the measurement period

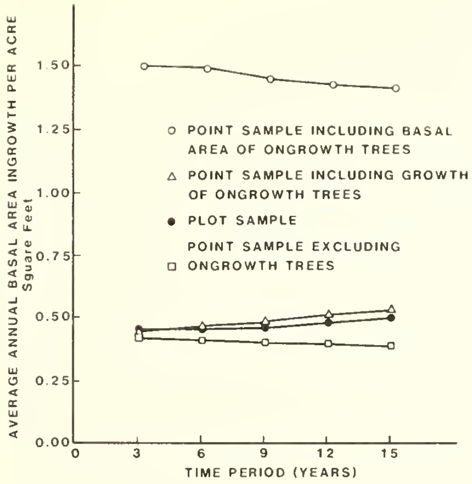

Figure 2.--Average annual basal area ingrowth per-acre estimates for various time periods. (Myers and Beers 1968)

The diameters are backed up to the beginning of the growth period and only trees "in" at the beginning of measurement period are used in the Grosenbaugh, Beers, and Miller-type stand growth estimator:

$$\hat{g}_{1_a} = [1/n] \sum_i \sum_j (1/p_{1_{ij}}) * g_{ij} \sum_i \sum_j (1/p_{2_{ij}}) * g_{ij}$$

"in" merchantable trees + ingrowth

$$= [1/n] \sum_i \sum_j STF_{1_{ij}} * g_{ij} + \sum_i \sum_j STF_{2_{ij}} * g_{ij}.$$

where

g_{ij} = is the growth of the jth tree on the ith point during the remeasurement period. The estimate of growth per acre based on the basal area at time of point establishment (after growth has occurred) is

$$\hat{g}_{2_a} = [1/n] \sum_i \sum_j (1/p_{2_{ij}})\, g_{ij} \quad \text{. . . "in trees"}$$

$$+ [1/n] \sum_i \sum_j (1/p_{2_{ij}})\, g_{ij} \quad \text{. . . ingrowth}$$

$$+ [\text{ongrowth}]$$

$$= [1/n] \sum_i \sum_j STF_{2_{ij}} * g_{ij}$$

$$+ [1/n] \sum_i \sum_j STF_{2_{ij}} * g_{ij} + \{\text{ongrowth}\}$$

where $\hat{g}_{2_a}$ is the average growth per acre experienced by survivors during the previous remeasurement period. If no ingrowth or mortality occurs in the immediate future and if the growth rate is the same as in the immediate past, $\hat{g}_{2_a}$ is a reasonable estimator of future stand growth.

Since $STF_{2_{ij}} < STF_{1_{ij}}$, it is obvious that the growth estimate $\hat{g}_{2_a}$ derived from "in" trees using the basal area at time of point establishment and the associated stand table factors $STF_{2_{ij}}$ will be less than the growth estimate $\hat{g}_{1_a}$ based on the diameters at the beginning of the period of measurement. The magnitude of the differences between STF_1 and STF_2 associated with a range of diameters and diameter increments is shown in figure 1. For example, for a 9-inch diameter tree with a diameter increment of 2 inches in the measurement period, STF_1 is 1.5 times greater than the STF_2 associated with its diameter at the end of the period. The tree's contribution to growth per acre based on the initial diameter is thus 1.5 times greater than its contribution would be if the final diameter is used. For older forests having large-diameter trees and relatively small-diameter increments, the difference between $STF_{2_{ij}}$ and $STF_{1_{ij}}$ will tend to be small. The inclusion of ongrowth complicates the comparison of the estimators $\hat{g}_{1_a}$ and $\hat{g}_{2_a}$.

If one wishes to augment a set of permanent growth points with growth data from temporary points, it is essential that the two sets of data share the same time frame. Combining growth estimates based on different time frames will provide results of questionable value.

CONCLUSIONS

A review of the literature addressing the problem of estimating stand growth from PPS sampling data indicates (1) that stand growth can be estimated with PPS sampling and (2) that the problem is complex. The problem of estimating stand growth with PPS sampling revolves around the structure of the estimator to be used and the treatment of sample trees, most notably ongrowth. It has been shown that the choice of the probabilistic structure, the stand table factors chosen, is critical. Foresters using PPS sampling for the first time to estimate stand growth should (1) review the literature to obtain an estimator whose statistical properties are known, at least to some extent, and (2) be sure they understand which population parameter they are estimating. Foresters already using PPS sampling to estimate stand growth should review the field procedures and the estimators being used to ascertain whether their current procedures and estimators are appropriate.

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GROWTH FROM VARIABLE PLOTS: WHO CARES?

John L. Teply

ABSTRACT: Although growth estimates are an important aspect of forest management, too often growth is viewed as an isolated factor, not as one of several factors affecting change. The critical question should be rephrased from "What is the volume and growth?" to "What is the volume and how has it changed?" Effective management decisions cannot be made with growth data alone.

INTRODUCTION

So far this morning, this panel has presented a wide range of concerns dealing with growth from variable plots. These concerns have revolved around the strengths and weaknesses of sampling for growth using such plots, as well as very technical aspects. By simply considering the discussion topics of this panel it should become clear that the most appropriate method to estimate growth is not always agreed on or at least not always used during data acquisition processes. I hope that no one expects to decide today whether one can or cannot estimate growth from variable plots. Rather, we should focus on potential difficulties of estimating an item called "growth."

One may assume from the title of my presentation that I have some reservations as to whether "growth" from variable plots is a major issue or simply a historic expectation deriving from plot measurement process. Those of you who have spent a great deal of time in forest sampling or who are interested in forest sampling may regard my view with some skepticism. A few years ago, I would have agreed that growth was extremely important and must be estimated at all costs. Even today, as I am redesigning the Pacific Northwest Region inventory process, growth is a major concern. But after the past few years of data analysis and presentation for the purpose of planning and making decisions, I have come to view growth as a factor that helps explain change rather than as a single estimation.

THE REAL PROBLEM

With this in mind, I would like to emphasize the application and use of estimated growth rather than the technical aspects of the variable plot. Regardless of how a growth estimate is obtained, it must meet the needs of those intending to use it. I realize now that the real problem is defining the critical question or questions before data are compiled. I failed to do this on 11 projects I have worked on by assuming that growth was a single element of interest rather than asking what significance it had to the larger picture of change. I now believe that variable "growth" has considerable significance to researchers and model builders but only limited value to decision makers if presented as an isolated piece of data.

I would like to take a short time to further define some of my background with regard to forest sampling so you may better understand how I came to be less concerned about the single estimate of growth. I worked for the Pacific Northwest Forest and Range Experiment Station during the mid 1960's as a member of their survey crew and in the early 1970's as a member of their compilation and analysis section. Later I worked with the U. S. Department of Agriculture, Forest Service, Pacific Northwest Regional Office, further analyzing compiled data. In 1979 I became responsible for the inventory program in the Pacific Northwest Region; this position encompassed design, compilation, analysis, and projection. Because the Forest Service has been compiling data for several decades, I assumed that the type of information necessary to meet the needs of planners and the Forests had been thoroughly defined and that this aspect did not need further consideration. Therefore, my first effort was to address the sample design and data acquisition of inventory as well as complete 11 Forest projects in the necessary time frame.

THE REAL QUESTION

With the completion of these projects, it became apparent that the question being asked by all parties impacted by planning decisions (What is the volume and growth?) is not the critical question. Further discussion reveals that the real question is, "What is the volume and how has it changed?" or, with silvicultural exams, "What is the response?" These questions have been repeatedly asked within the last 24 months by Directors, Timber Staffs, Forest Supervisors, industry, industry associations, and consultants. No one stops with the question, "What is growth?" Growth is usually the term used to initiate the question, but the answer is expected to be in terms of change. These change data have been requested at the plot level, the strata level, and the Forest level so that managers can determine how volume has changed and why.

Paper presented at: Growth and Yield and Other Mensurational Tricks: A Regional Technical Conference, Logan, UT, November 6-7, 1984.

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To better answer questions regarding change, we have started redesigning the data acquisition process for our inventory. This has encompassed the evaluation of the types of volume as well as the types of growth that may occur on a plot between inventories. The issue is to identify the real change at the plot level, which should encompass the difference between d.b.h. measurements and diameter increment borings, ingrowth volume and growth on ingrowth, ongrowth volume and growth on ongrowth, and growth on mortality to simply restate items already mentioned. We have come to believe that the real need in the estimation process, regardless of the type of plot, is the ability to determine the significance of volume change over time, which i not completely answered with the estimate of growth on green trees or crop trees. It is essential that management or planning decisions reflect an awareness of change along with growth but not just growth.

We are in no way attempting to eliminate or ignore the needs of research and those involved in building projection models that are limited t growth estimates, but we do feel that both interests can be met and are necessary.

MORTALITY ASSESSMENT: WHAT ARE THE ESSENTIALS?

Roland G. Buchman

ABSTRACT: A forest inventory, individual-tree mortality and growth models, and a computerized forest projection system are the essential elements for assessing regular mortality. The key items for each element are described and additional detail is given for the mortality model and the projection system. Discussion centers on the PROGNOSIS, STEMS, and TWIGS systems.

INTRODUCTION

Here today--but what about tomorrow? We can't sample future mortality, although we need this information for resource planning and treatment scheduling. However, the experience we've accumulated from remeasured permanent plots can be extended to the future forest. We can achieve this through projecting the current forest inventory for 5, 10, or more years using computerized mortality and growth models.

Mortality assessment using individual tree records is important because detailed tree information supports silvical decisions for planning treatments and estimating product yields as part of resource planning. In addition to retaining the tree detail present in a forest inventory, individual-tree mortality models facilitate assessment under a wide range of forest conditions.

Regular mortality--that caused by suppression, aging, pests at endemic levels, and competition for space, nutrients, and moisture--is always present; part of forest resource assessment, it can be estimated using the inventory data commonly recorded. Several regional models based on extensive information from remeasured plots are available for this use now; others are being developed.

This report presents the essential elements (the forest inventory, the individual-tree mathematical models, and the computerized system) for assessing regular mortality. Indepth discussion of mortality models and projection systems centers on two major, widely applied forest growth and yield projection systems.

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BACKGROUND

Mortality can be assessed with a one-time forest inventory. The resulting estimate is easily biased, however, because of the difficulty in determining the year of tree death or disappearance of dead trees. For these reasons, it is common inventory practice to restrict recording of dead trees to those dead 3 years or less (USDA Forest Service 1981; Bengston 1983). Recent tests show that large-scale aerial photography can identify current-year deaths, but under limited conditions (Hamilton 1980b).

To predict future mortality, we can apply the experience accumulated from remeasured permanent plots and described through mathematical models to project today's stand into the future. By restricting the projection to 1 year, we can estimate current-year mortality. Common practice is to mathematically describe permanent plot mortality information and apply these models in assessing current-year and future mortality. Hamilton (1980a) points out that the small size of most inventory plots makes them inefficient for obtaining mortality data. Buchman and Shifley (1983) identify a further limitation: many classes of trees were poorly represented on the early growth and yield plots.

Remeasured permanent plots provide critical information--the time interval of death for each dead tree and previous characteristics such as diameter and diameter growth rate for all trees. Competition can be determined by consolidating the tree information on a plot. Reliable mathematical models can be derived from frequent measurements over relatively long periods of observation.

Permanent plots were established in the early 1900's to provide data for survival tables and on growth and mortality (see, for example, Deen 1933; Krauch 1930). Repeated measurements on extensive sets of permanent plots have provided the mortality base for individual-tree mortality models for 19 species of the Lake States (Buchman 1983; Buchman and Lentz 1984), 11 species of Montana and northern Idaho (Wykoff and others 1982), and 22 species groups of the Central States (USDA Forest Service 1983). There are many sets of mortality data and models (Dudek and Ek 1980; Trimble and Shriner 1981).

Monserud (1976) and Hamilton (1980a) thoroughly discuss the data requirements for modeling mortality and the statistical methodology. Buchman and others (1983) relate the model form to survival expectations based on tree species, size, and vigor.

When used in forecasting, models are applied in another time, the future, and to the gamut of forest conditions, including size-vigor tree classes not encountered in their development. Buchman and Shifley (1983), in describing their experiences in developing and applying individual-tree mortality models for the Lake States and the Central States, point out the demands that forecasting places on these models.

ESSENTIALS

As pointed out earlier, it is possible to assess current-year mortality with just one on-the-ground inspection and, under restricted conditions, through large-scale aerial photography. However, reliable mortality estimates with these methods are possible for only very short time horizons.

Assessment of future mortality depends on the projection of a representative forest inventory. When this process is applied to a current inventory for a 1-year projection, it provides an estimate of current mortality.

Thus, assessment of future mortality requires the forest inventory data, models to project mortality based on the inventory, and a projection system. The forest inventory is basic stand information assembled to estimate forest yield by product, schedule harvests, or make silvical decisions. Included are individual tree records containing species identification, diameter, status, and quality. Also needed are some measure of plot productivity and derived stand characteristics such as basal area and average diameter. Most inventories contain many additional items; the above provide the information required for using the mortality models and for forecasting growth and yield.

Mortality models commonly depend on the species of the tree and its size and/or vigor. The mortality model in PROGNOSIS, a growth and yield projection system widely used in the Northern Region of the Forest Service, is based on tree species and d.b.h., quadratic mean stand diameter, habitat type, trees per acre, and stand basal area (Wycoff and others 1982). STEMS, a growth and yield projection system widely used in the North Central Region, requires d.b.h. and diameter growth rate in its Lake States variant (Belcher and others 1982) and d.b.h. and basal area of larger trees in its Central States variant (USDA Forest Service 1983). Competition indices, correlates of tree vigor, are commonly used in mortality models (Monserud 1976).

However, mortality models alone can't assess future mortality. They must work in conjunction with models that grow each tree and provide updated tree values to interact with the mortality model.

Finally, these models--mortality and growth--must be contained in a computerized system if they are to be applied to extensive data sets such as a forest inventory. To project the inventory, the system must be compatible with the inventory methods and data, be applicable for all timber types and stand conditions encountered in the inventory, and treat the stand as the basic unit, with projections depending upon interactions among the trees within the stand (Wycoff and others 1982).

Essentials for estimating mortality are the forest inventory, the models for mortality and growth, and the projection system. Additional description of forest inventories and growth models within projection systems can be found elsewhere (USDA Forest Service 1981; Wykoff and others 1982; Belcher 1981).

MORTALITY MODEL

Buchman and Shifley (1983) emphasize that extrapolation is involved in estimating mortality by applying remeasured permanent plot information to the forests of tomorrow and to forest conditions differing from those of the permanent plots. Mortality models must have a theoretical and empirical foundation to justify this extrapolation.

The theoretical model form (fig. 1), used for species within the Lake States, is based on biological principles and extensive tree survival data (Buchman and others 1983). This form is based on three premises:

1. The mortality probability for vigorous trees is low, but not zero. This limiting value has little relation to tree size.
2. Not all trees of low vigor will die. This probability depends on tree size; the lowest mortality occurs somewhere beyond the juvenile stage but before senescence.
3. The mortality rate decreases rapidly as tree vigor increases.

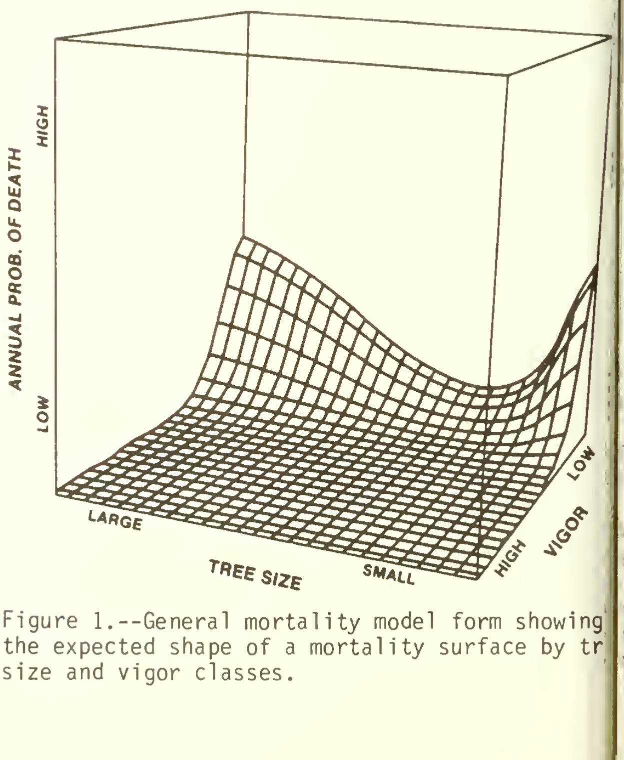

Figure 1.--General mortality model form showing the expected shape of a mortality surface by tree size and vigor classes.

These premises are consistent with the model constraints suggested by Monserud (1976) and Hamilton (1980a), but provide additional guidelines for mortality estimates for trees whose measures were not within the model's data base. In particular, these additional guidelines helped specify the probability of mortality for large, slow-growing trees and for 1- to 3-inch trees (Buchman and others 1983).

Validating the model by applying it to forest inventories independent of those used in developing the model provides the following information on extrapolation problems: (1) how the model performs on those tree size-vigor classes not present in the development data; (2) how well models developed from remeasured research plots apply to general National Forest land; or (3) how well models from fixed plot sizes apply to 10-point clusters, wherein each application involves some degree of extrapolation. Validation is important for building confidence in the model, for knowing where and when it will perform satisfactorily, and for estimating its accuracy and precision.

Finally, good mortality model performance depends on having good tree-growth information. The mortality model is usually blamed whenever poor tree survival predictions occur. However, mortality models do not operate independently from growth; we must also consider the quality of the growth information.

PROJECTION SYSTEM

PROGNOSIS and STEMS, two projection systems referred to earlier, can project the growth and mortality of a forest's trees using commonly gathered inventory data (fig. 2). They are individual-tree-based systems applicable to the wide range of forest conditions in their respective regions. These systems retain the inventory tree detail needed to support silvical decisions and product yield estimates.

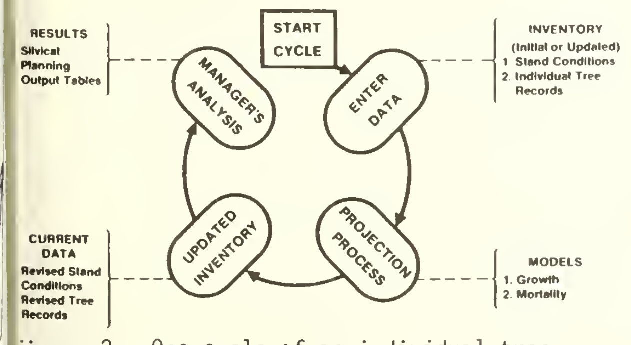

Figure 2.--One cycle of an individual-tree projection system.

Both systems readily provide the future inventory base for a mortality estimate for a survey unit, a State, or a large region. At any point in the projection schedule, they can provide the tree information that corresponds to an inventory for that moment in time.

Both systems' growth and mortality projections center on the interaction among trees within the stand. Key to this are the individual tree records that contain each tree's species and diameter. Additional ingredients include either plot size or basal area factor, or each tree's area expansion factor and stand characteristics required for estimating productivity. A detailed description of the input can be found in the user's guides (Wykoff and others 1982; Belcher 1981).

Although my discussion has centered on STEMS and PROGNOSIS, other systems are in place. For instance, the Multipurpose Forest Projection System (MFPS) has been adapted to some western forests and to forest areas in different sections of the eastern United States. The Cooperative Redwood Yield Project Timber Output Simulator (CRYPTOS) and its companion, CRYPT2, are designed for the northern coastal region of California.

Today, mortality can be assessed for individual stands by using a microcomputer. TWIGS (Belcher 1982), the North Central Station's system with Lake States and Central States variants, uses the same tree and stand input and the same growth and mortality models as STEMS. With TWIGS and a microcomputer, we can readily view the future of a stand and assess tree mortality.

WHAT NEXT?

Continuing evaluation of current mortality models and projection systems will better describe their performance and pinpoint areas requiring additional research. For example, mortality models need further evaluation with application to small trees and to large, slow-growing trees. Projection systems need evaluations under a wide range of forest conditions (Holdaway and Brand 1983). We must continue to evaluate and assemble experiences from varied applications of each system.

Planning is under way within each Forest Service Region to establish a coordinated growth and yield system. This should lead to improved and more extensive mortality models and projection systems.

Means for calibrating systems for local use will be developed. PROGNOSIS provides for self-calibration through entering previous growth information along with the forest inventory (Wykoff and others 1982). Research is under way to develop the means to modify STEMS projections on the basis of local climatic factors and soil productivity.

Additional microcomputer systems, comparable to TWIGS, will be developed to facilitate individual stand assessment.

A general procedure for assessing mortality under the more extreme tree stresses, including catastrophic conditions, is also needed but it is of lower priority than the other items. This procedure should include the means to adjust for long-term climate changes. Hamilton (1980a)

presents an approach for catastrophic mortality. Even greater benefit will accrue from a system that recognizes the varied levels and patterns of stressful conditions. PROGNOSIS extensions are available to simulate outbreaks for three insect pests (Wykoff and others 1982).

SUMMARY

A representative forest inventory, models for mortality and growth, and a projection system are the essentials for assessing current-year or future mortality. Inventory procedures that have been in use for many years provide the needed data.

Individual-tree mortality models have recently been developed that encompass the wide range of forest conditions of a region. Much work remains before all regions have the requisite models and computerized systems.

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DENSITY MANAGEMENT DIAGRAMS: A PRACTICAL APPROACH

James N. Long and James B. McCarter

ABSTRACT: Density management is the control of growing stock to achieve particular management objectives. A density management diagram was constructed for lodgepole pine in the central Rocky Mountains. To use the diagram, management objectives must first be translated into specific target levels of growing stock (stand density index). In principle, the stand is allowed to grow to the targeted upper limit of growing stock, is thinned down to the lower limit, and the process repeated as many times as necessary. In practice, modification of this simple process is usually needed. Density management diagrams are potentially valuable tools for density management planning. Although they will not replace more sophisticated computer growth and yield models, they can, together with site index curves, equations, or tables, be used by the forester to generate reasonable approximations of growth and yield for density management regimes.

INTRODUCTION

Density management is the control of growing stock to achieve particular management objectives. Although the actual control of growing stock through initial planting density or subsequent thinnings is fairly easy, deciding on appropriate levels of growing stock, given a particular management context, is much more difficult.

Various approaches to this problem have included the "seat-of-the-pants" or "30 years of experience" approach, or both; various rules-of-thumb, such as "d.b.h. times" and "d.b.h. plus" (Smith 1962); and the use of growth and yield models. All of these approaches have their advantages; they all have serious limitations.

Density management diagrams represent a practical approach to density management planning. The objectives of this paper are to briefly describe density management diagrams and to illustrate their potential with a diagram constructed for lodgepole pine (*Pinus contorta*) in the central Rocky Mountains.

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DENSITY MANAGEMENT DIAGRAMS

Density management diagrams are simple models of dimensional relationships presented in a graphic form. They are, in essence, simple stand average models. The diagrams, in their various forms, are based on one of several predictable size-density relationships. The most familiar of these, at least in the ecological literature, is the -3/2 self-thinning rule which relates mean tree volume to density of crowded stands. Similar, and mathematically related, size-density relationships include those relating mean height to density (Wilson 1979) and mean diameter to density (Reineke 1933).

Indexes of stand density based on size-density relationships have several characteristics which make them excellent tools in density management. For example, they are, for crowded stands, highly predictable. They are independent of site quality and stand age. And perhaps most importantly, they are excellent predictors of levels of competitive interaction, for example, growth-growing stock relations and degree of site occupancy (Long and Smith 1984).

The simplest density management diagrams are basic two-parameter models. For example, Reineke (1933) constructed a nomogram (fig. 1) relating quadratic mean diameter (Dq) in inches, trees per acre (TPA), and stand density index (SDI). Wilson (1979) devised a similar diagram equating mean height, density, and index of stand density based on spacing as a percentage of height. The most familiar density diagrams are of the type developed by Gingrich (1967). These diagrams relate Dq, stand basal area, density, and levels of growing stock (fig. 2). Commonly in the Gingrich-type diagrams the levels-of-growing-stock lines are based on crown competition factor (CCF) (Krajicek and others 1961).

To use such a diagram, management objectives must first be translated into specific target levels of growing stock. In principle, the stand is allowed to grow to the targeted upper limit of growing stock, is thinned down to the lower limit, and the process repeated as many times as necessary (fig. 3). In practice, modification of this simple process is usually needed to accommodate some aspect of the management objectives such as minimum merchantable tree size or minimum volume removal per entry. Appropriate upper and lower limits will, of course, vary with both species and management objectives.

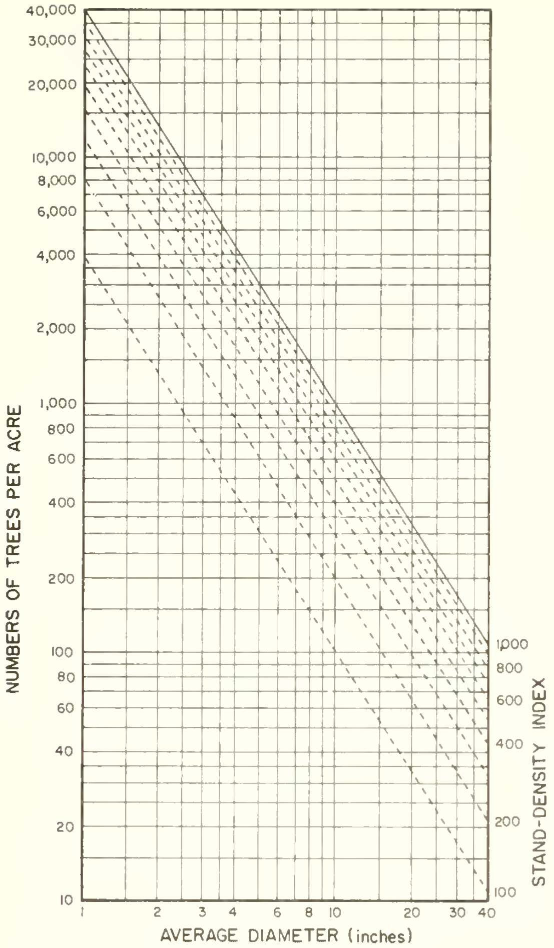

Figure 1.--Nomogram relating Dq, TPA, and SDI (Reineke 1933).

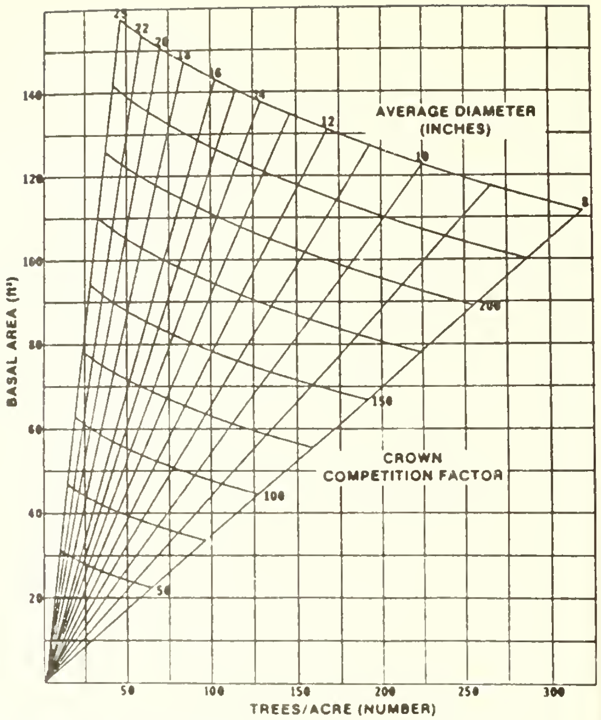

Figure 2.--Stocking guide for black walnut (Schlesinger and Funk 1977).

For a given species, dimensional relations are fairly predictable. Therefore it is possible, with the inclusion of additional size parameters, to greatly improve the utility of a diagram with but a slight increase in its complexity. Figure 4 is a density management diagram constructed for lodgepole pine, in the central Rocky Mountains (McCarter 1984). This diagram has Dq and TPA on the two major axes; both are plotted on a logarithmic scale. The parallel diagonal lines represent SDI. The uppermost line corresponds to an SDI of 700, approximating the maximum combination of Dq and TPA possible stands of this species. The two additional sets of lines represent mean height of site trees (Hs) and total volume. Similar density management diagrams have been developed for many of the commercial timber species of Japan (Ando 1968), coast Douglas-fir (*Pseudotsuga menziesii*) (Drew and Flewelling 1979), loblolly pine (*Pinus taeda*) (Flewelling 1981), as well as lodgepole pine (Flewelling and Drew in press).

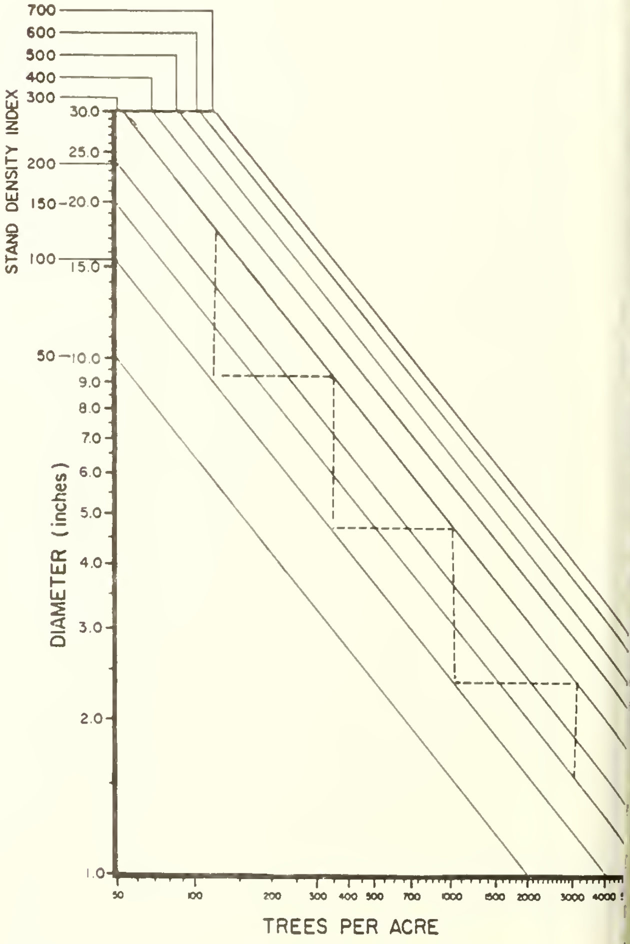

Figure 3.--Hypothetical density management regime using SDI to set upper and lower limits of growing stock.

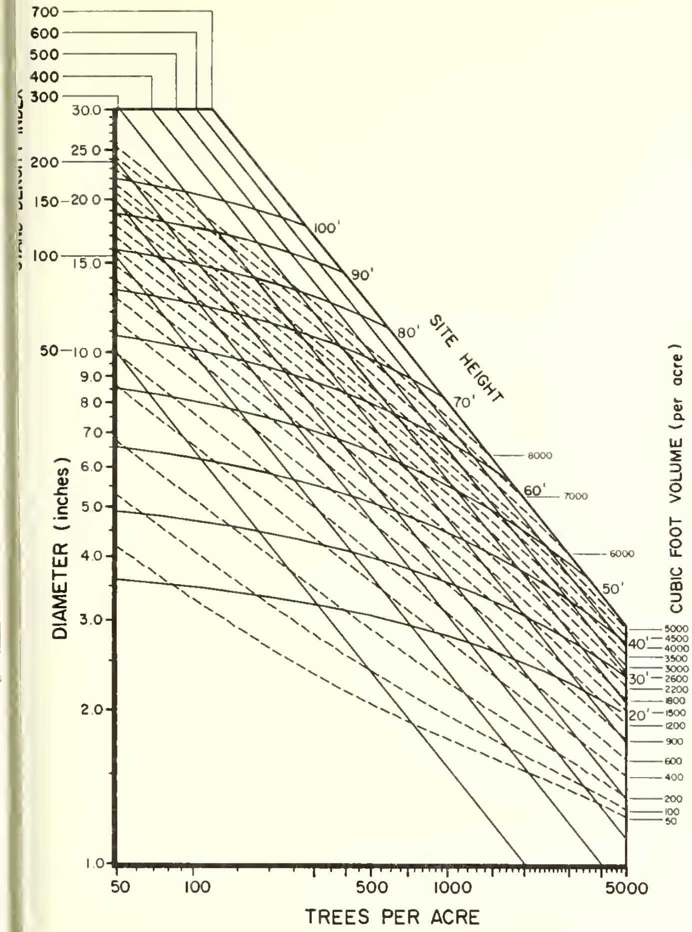

Figure 4.--Density management diagram for lodgepole pine. (An 8½- by 11-inch copy of the diagram is available, on request, from the authors.)

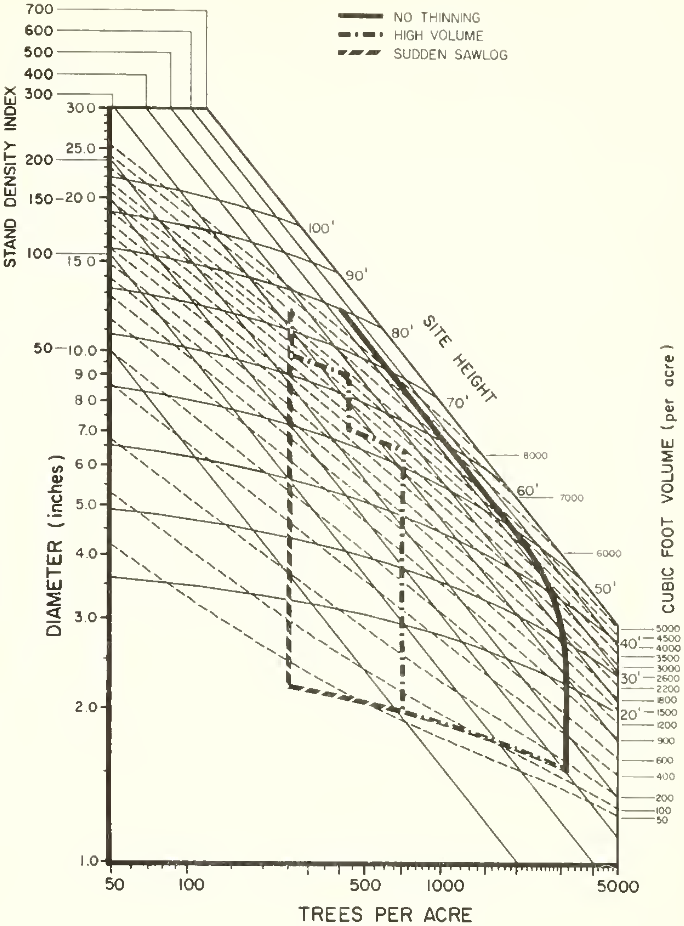

Figure 5.--Alternative density management regimes.

USE OF THE DENSITY MANAGEMENT DIAGRAM

Potential uses of the density management diagram will be illustrated by example. Figure 5 illustrates three alternative density management regimes for a hypothetical lodgepole pine stand with 3,050 TPA and Dq equal to 1.5 inches. Site index (base age 100) is assumed to be 80. It is also assumed that commercial thinning requires a Dq of at least 6 inches and a volume removal of at least 1,000 ft³/acre/entry. Under each of the alternative regimes, an end-of-rotation Dq of 12 inches is assumed.

In the first, or no thinning, alternative, Dq and Hs increase with little, if any, reduction in TPA until the stand begins to self-thin (SDI > 400). Subsequent increases in average size are accompanied by declining TPA so that SDI remains more or less constant at a level somewhat below the species maximum (Drew and Flewelling 1977).

Because mortality which may occur before onset of self-thinning is exceedingly difficult to predict and is largely independent of density (Drew and Flewelling 1979), in most cases it should be ignored in the planning of density management regimes.

Time can be included in this development by the use of site index curves or tables and the estimates of Hs from the diagram. For the no thinning alternative, when Dq equals 12 inches, the estimate of Hs is 80 ft. Lodgepole pine variable density site index tables for SI_{100} = 80 ft (Alexander and others 1967) indicate a rotation age of about 132 years (table 1). The increase in age beyond that suggested by the site index (that is, 132 years versus 100 years when Hs = 80 ft) reflects the negative interaction between height growth and density incorporated into the Alexander and others (1967) tables.

In using the diagram to plan a density management regime it is necessary to first translate the management objectives into appropriate levels of growing stock, that is, upper and lower limits to SDI. For example, the second, or high volume, alternative is designed to maintain levels of growing stock sufficient to insure full site occupancy (SDI > 250) but avoid self-thinning (SDI < 400). In this regime we actually use SDI = 350 as the upper limit to growing stock. This somewhat low value, as opposed to 400, illustrates the idea that minimum levels of individual tree vigor may often be a factor in density management planning. Berryman (1982) suggests, for example, that reducing competition and thus increasing tree vigor may represent the best silvicultural insurance against catastrophic losses to the mountain pine beetle.

Table 1.--Comparison of three density management alternatives[1]

	Age	Hs	TPA Before	TPA After	Dq Before	Dq After	Volume removed
	Years	Feet			Inches		Ft³/acre
			No-thinning				
Final harvest	132	80	410		12.0		8,500
Total yield							8,500
MAI							64 ft³/acre/yr
			High volume				
PCT	5	8	3,050	700	1.5	2.0	
CT1	65	54	700	440	6.4	7.2	1,000
CT2	83	65	440	250	8.8	9.6	1,000
Final harvest	104	76	250	0	12.0	0	6,000
Total yield							8,000
MAI							77 ft³/acre/yr
			Sudden sawlog				
PCT	5	8	3,050	250	1.5	2.2	
Final harvest	95	76	250	0	12.0	0	6,000
Total yield							6,000
MAI							63 ft³/acre/yr

[1] Mean annual increment based on age at final harvest; includes yield from commercial thinnings and final harvest only.

The target end-of-rotation Dq (12 in) and growing stock upper limit (SDI = 350) define a stand with approximately 250 TPA and 6,000 ft³/acre. It is then easy to work backward through the rotation as indicated on the diagram (fig. 5). A precommercial thinning is required to set up the first commercial thinning. With two commercial thinnings and the final harvest, this regime yields an estimated 8,000 ft³/acre and mean annual increment (MAI) of about 77 ft³/acre/yr.

The third, or sudden sawlog, alternative uses the same growing stock upper limit (SDI = 350) but eliminates the commercial thinnings. A heavy precommercial thinning is used to set up the final harvest. This regime emphasizes the production of final crop trees in a relatively short rotation (95 years) at the expense of some potential yield (table 1). Compared with the high volume alternative, this regime reduces total yield by 33 percent, but because of the shorter rotation reduces MAI by only 18 percent.

The graphical representation of dimensional relationships by density management diagrams can provide a great deal of insight into the way that even-aged stands develop. For example, the tradeoff between either rapid individual tree growth and short rotations or greater yields associated with higher levels of growing stock is easily illustrated with the diagram. The consequences to growth and yield of various management objectives and constraints can be interpreted using the diagram. If, for example, the minimum Dq assumed to be required for a commercial thinning entry was reduced, the total yield and MAI of our high volume regime could be substantially increased.

Density management diagrams represent potentially valuable tools for density management planning. Their incorporation of size-density based indexes of growing stock (for example, SDI) provide the user with a mechanism with which to quantify those aspects of stand and individual tree performance important in the context of specific

anagement objectives. Although density management diagrams will not replace more sophisticated rowth and yield models, they can, together with ite index curves, equations, or tables, be used o generate reasonable first approximations of rowth and yield for density management regimes.

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CALIBRATION CONSIDERATIONS IN USING MAJOR MODELING SYSTEMS

Ralph R. Johnson and Gary E. Dixon

ABSTRACT: The Stand Prognosis Model has been recalibrated for areas in the northern Rockies, central Rockies, and Pacific Northwest. In addition to the mechanics of refitting growth and mortality functions, other items have surfaced that add to the complexity of moving a major model to a new area. Field visits by modeling personnel are mandatory. Aggregating data from a variety of sources, understanding what data you have, how it was collected, and its integrity is time consuming. Growth and mortality models need to reflect the kind of data available and local biology. Recalibration needs to be linked with training new users. As new models are brought into a production mode, computer code upgrades and documentation become more complex, as is the interface of users with the new model.

INTRODUCTION

Over the past 6 years, the Stand Prognosis Model (Stage 1973) has been recalibrated for a number of forest conditions in the Western United States (fig. 1).

Figure 1.--Location of geographic variants of prognosis in the Western U. S.

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In the process of recalibration, many lessons have been learned about moving major models to new areas. Examples given in this paper illustrate these lessons. Not all of them are mensurational. Mathematical models must be embedded in computer code, and users must be trained to use the completed program. Once the system is built, maintenance, support, and enhancement are required. This paper covers the broader subject of moving, maintaining, and supporting the complete model, not just the mensurational aspects.

BUILDING THE SYSTEM

Developing Local Knowledge

Often the mensurationist is given data sets for an area and asked to produce functional relationships from them. If the mensurationist is not familiar with that area, it is easy to miss a key variable or not know when something is out of whack.

One of the first steps in the recalibration process is a field visit, which may yield local sources of data that are unknown to the central office. Discussions with field personnel provide insights about data integrity and history that affect the modeling process and are not included in any written documentation. When a user's data and ideas are considered in the modeling process, user confidence in the model is enhanced. In our present project in south-central Oregon and northeastern California, such a trip surfaced enough information to require an additional 2 months of data acquisition and aggregation. This resulted in a large amount of managed stand data that bolstered user confidence and enhanced the model.

The field visit opens communications with the user community. Users become familiar with those who did the work and feel more free to critique and use the final product. It's easier to talk on the phone to someone when you can visualize their face, and future contacts will most likely be by phone or letter. Field personnel are invaluable in the critique phase of model development.

During the field trip, open discussion can take place about handling unique conditions and the various types of information needed to run the model. Some examples of unique conditions requiring special consideration are hardwoods in the Klamath Mountains, pumice soils in eastern Oregon, and mountain pine beetle in the Tetons.

ıggregating Data to a Common Computer

:urtis' (1983) detailed discussion of items ıeeded for growth and yield research on ıermanent plots is invaluable for anyone using lata from a variety of sources. The appendix of urtis' paper lists key variables that are mportant in recalibrating PROGNOSIS models. ariables as minor as month of survey are critical f growth is recorded by remeasurement. requently, an apparently good data set is ıissing a significant variable, but this is ifficult to determine without a complete list of ariables. In the case of PROGNOSIS recalibration, ome measure of tree vigor (for example, crown atio) has typically been missing.

he sample design must be known for each data et. Was the sample taken with fixed area plots, ariable radius plots, or a combination of plot ypes? We require a plot installation and code nterpretation manual with each data set we eceive. Frequently, careful reading of the nventory instructions and codes manuals reveals hat some trees were not recorded. For example, ough cull and cull saplings may not be recorded n some inventories. In these cases, growth ecords may be biased toward "best" trees.

roblems usually arose with the measurement of ortality. Were trees killed by insects or isease? Were trees recently removed by logging r dead before removal? In forest inventory, ortality is often coded as recent (last 5 years) r older dead (more than 5 years). We have erious concern about the ability of cruisers to stimate the age of mortality that accurately.

ifferent units of measure for the same variables ıst be reconciled before data can be aggregated. s we have moved PROGNOSIS to new geographic reas, we have encountered a variety of measures f productivity. Some areas use habitat types, ome use site index, and still others use soil ypes. Site index differences are another good xample. In the same geographic area, different dministrative units use different site index ırves for the same species.

ccessing data sets that are not the most current lited version is another problem. A given dministrative unit's computer file may resemble ıother's on the outside. On the inside, however, ıey may be different, and using the old file can e a costly mistake.

ılculating the Stand Variables

ı building PROGNOSIS models, individual tree ecords are the basic record; however, stand ttributes need to be attached to them. Basal ea per acre, crown competition factor, top ight, trees per acre, and the tree's social sition are calculated. Stand values are lculated for the beginning and end of the owth period. The importance of knowing the ta and getting it standardized cannot be erstated. Getting the wrong basal area factor or wrong mortality estimation procedure will lead to an incorrect result.

The PROGNOSIS model has until recently been built using 10-year growth periods for big trees. If the inventory remeasurement period for a particular data set was 8 years, it must be adjusted to a 10-year measure so it will be compatible with the other data sets. Although increment cores are usually read for the last 10-year growth interval, we have encountered plots with increment recorded in rings per inch. These kinds of anomalies are uncovered by reading the manuals and talking to owners of the data.

Data Editing

Once the data are in a common computer file, scattergrams and descriptive statistics are used to look for errors. Data listings should also be examined to look for summarization program problems. As an example, in our analysis, a point crown competition factor (CCF) variable was printed and written to a mass storage file; however, only a subset of the data was printed and used in error checking. When the whole data set was examined, the point CCF variable was constant for records after the print was stopped. The problem, an errant GO TO statement, was quickly located and corrected.

Getting good clean data from which to build a model is a time-consuming and demanding job. In our experience, this has typically taken about 4 months, unless all of the available data are from one source. Even with one source, the data usually have been collected over a number of years, during which coding conventions have changed.

Fitting Models

For the geographic variants we have developed, growth and mortality submodels were refit while the basic operating system was essentially unchanged. We wanted a model that reflected local forest conditions but that was still a PROGNOSIS model. Of the parts we have refit, some items are worthy of note.

Volume equations should be local. They should be the same ones used in stand examination programs and cruising programs. Incompatible equations result in frequent phone calls from users asking why the answers are different. Having separate equations for merchantable products and total cubic volume leads to the same inconsistency. A taper equation with a mathematically compatible cubic equation is preferred. Board foot volumes can also be derived from the taper equations. In addition, the equations must account for a wide array of merchantability standards since a model built today will be used tomorrow, and merchantability standards are constantly changing. We tried using form class equations, but the results were unacceptable. It was difficult, if

not impossible, to allow for change in form class over time and with changing tree conditions.

Height growth measurements are plagued with measurement errors and lacking in most data sets. Felled tree studies are the best solution to this problem. Although these studies are expensive, a variety of growing conditions can be sampled for and, if stem measurements are made at the time of felling, the trees can be used for volume table construction.

In the present variants of PROGNOSIS, height growth is treated differently for large and small trees. Small tree projections are made using a 5-year model; large tree height projections use a 10-year model. Five-year height growth measurements for small trees have been collected for several years in the stand exam process in the Northern Region. Unless trees are in plantations (rapid growing), measuring height growth without destructive sampling is difficult for trees over 2 inches d.b.h. For species like western redcedar (Thuja plicata) and hemlock (Tsuga heterophylla), destructive sampling is even necessary for trees less than 2 inches d.b.h.

Height growth is further complicated by defoliation caused by pests such as western spruce budworm. When defoliation has occurred, it should be indicated on the data set. Forest Pest Management has overlaid budworm defoliation maps on stand maps to determine what stands are likely to be influenced by the budworm.

Large tree height growth models have taken two basic forms. Wykoff and others (1982) present log linear models used in the Inland Empire variant of PROGNOSIS. When height growth data are available, the log linear form is used. Lacking height growth data, a technique using the Johnson (no relation to this author) SBB distribution is used (Schreuder and Hafley 1977). Figure 2 illustrates the form of this distribution. Figure 3 illustrates the data set used to fit the distribution. We fit the SBB distribution to trees of selected attribute classes such as crown ratio, site index, habitat type, and basal area in larger trees. Diameter growth drives this model, and a tree is assumed to maintain the same relative position in the distribution from the beginning to the end of the projection period.

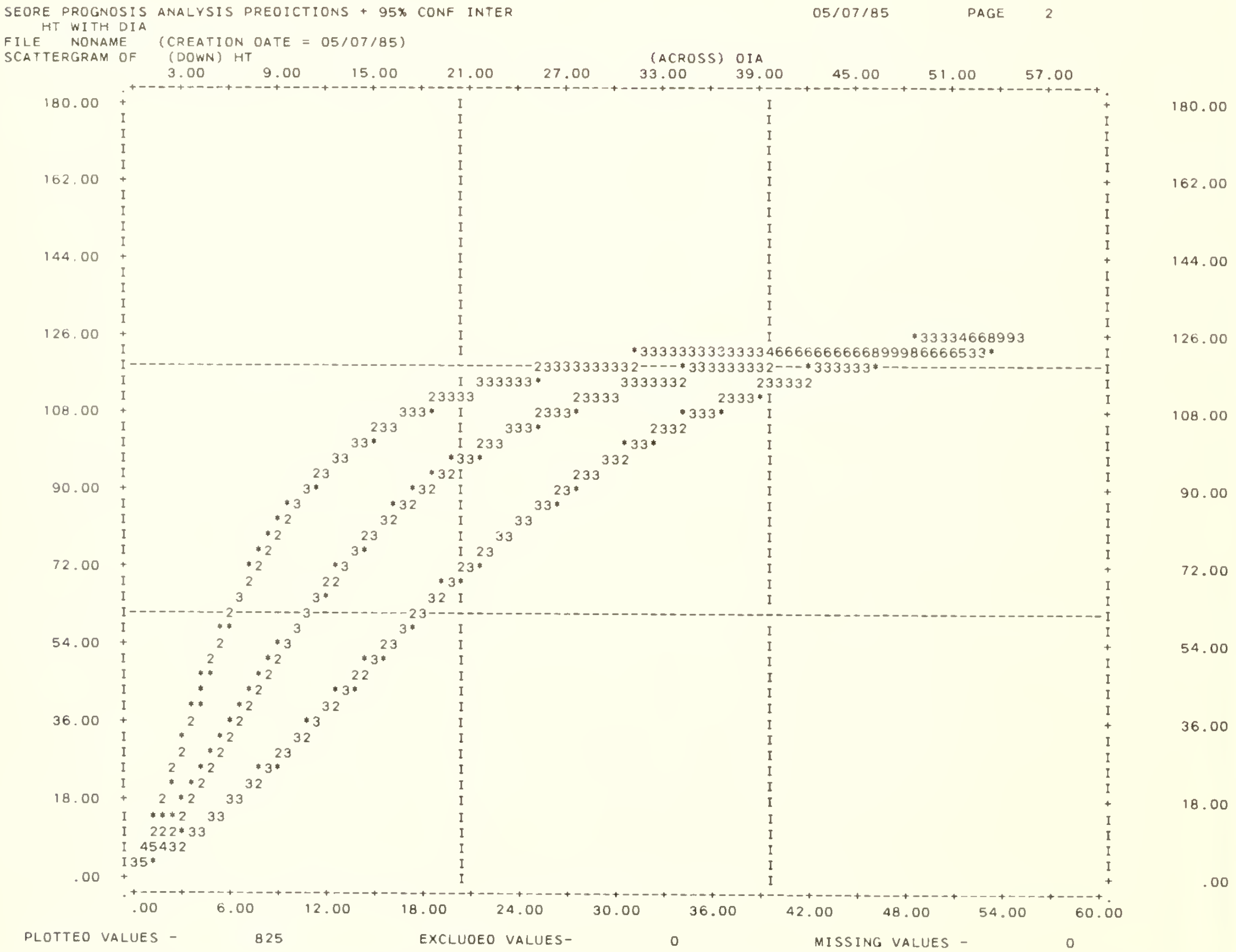
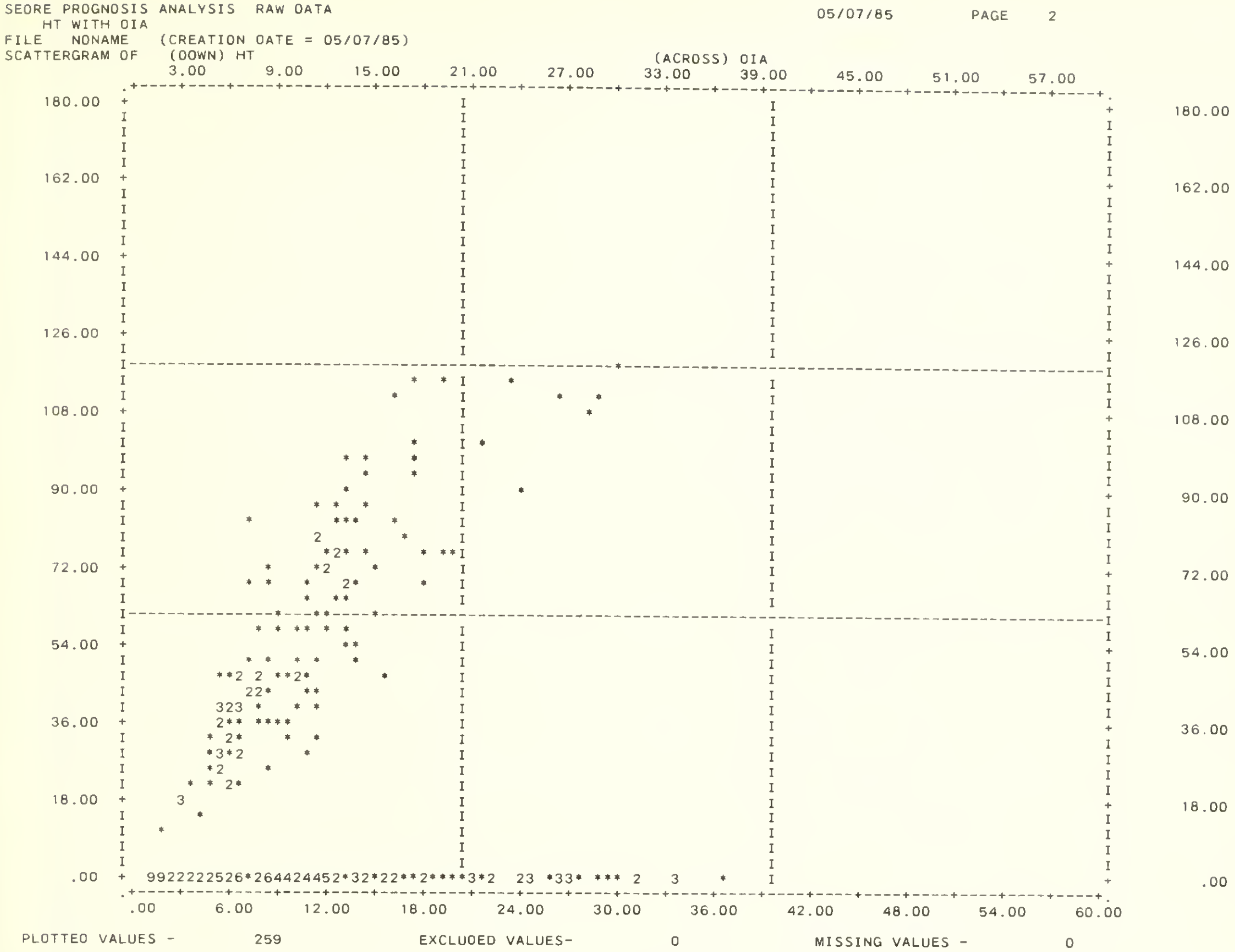


Figure 2.--Plot of median, upper 95 percent confidence band, and lower 95 percent of Johnson's S_{BB} distribution for ponderosa pine (Pinus ponderosa).



igure 3.--Scattergram of heights with diameters for data used in fitting the S_{BB} distribution plotted in igure 2.

iameter growth models have taken two forms. ykoff's log linear forms are used for conifers nd a nonlinear form is used for hardwoods. In he Utah variant of PROGNOSIS, we used an daptation of Wykoff's forms suggested by Stiff nd others (1982) for conifers. This adaptation ses point density as well as, or in place of, tand density. For aspen (Populus tremuloides), e used nonlinear equations of the type used in he STEMS Lake States Models (Holdaway 1984). lacement of STEMS-type equations into the ROGNOSIS superstructure was accomplished with ew computer code modifications.

itting diameter growth models is greatly nhanced by a well-thought-out and debugged nalysis package. Such a package, developed by ykoff, is being used in our refitting of ROGNOSIS. These routines use a combination of ustom and commercial software. REX (Grosenbaugh 967) and SPSS comprise the core of the package. ven the use of Wykoff's analysis package equires recoding to accommodate variables unique o the data being analyzed.

Mortality functions have taken a variety of forms. The new techniques of Hamilton (1984) or Buchman (1979) require a growth measure not available in our data sets, so we could not fit such equations. In the Utah variant, mortality rates were based on inventory estimates of 5-year mortality. Diameter was used as reported in Wykoff and others (1982), in addition to a social position and density variable. The normal stocking density equation was refit to inventory records in the Utah, Teton, and south-central Oregon/northeastern California geographic variants. In eastern Montana, we used techniques described in Wykoff and others for mortality estimation; however, the estimates were adjusted using results of large-scale aerial photography (Hamilton 1984).

National Forests in the Inland Northwest are installing permanent plots which will be used in providing data for developing future mortality models and testing existing models. Through permanent plots, actual mortality and growth can be monitored.

MAINTENANCE AND SUPPORT FOR A MAJOR MODELING SYSTEM

Once a model is built, whether it is entirely new or a recalibration of an existing model, it must be maintained and supported to be accepted for widespread, long-term use. Potential users must be trained to use the model and frequently require assistance in error tracking when problems arise. Model errors must be corrected as they are discovered, and model adjustments may be necessary as the model is applied to a wide variety of situations. Additional features may be requested, and links to auxiliary routines might be necessary. If maintenance and support are lacking, users may become discouraged and stop using the model or attempt to maintain it themselves. User maintenance quickly leads to many slightly different versions of the same model, all of which are inconsistent with each other, and none of which have all the errors and inconsistencies removed or the latest enhancements incorporated.

Model Implementation

When a model is ready for implementation, it should go through a prerelease testing phase consisting of two or more steps. These steps may be lengthy and rigorous and, in some cases, several iterations may be required. The purpose of this phase is to make sure the model is behaving properly mathematically, biologically, and intuitively, given a limited range of input specifications.

The first step is to make sure the model is functionally correct. Typically, only the model developers are involved at this point. The model is run on a test data set and the output examined. General relationships are checked first. Examples would be tree (or stand) height increasing as diameter increases or the number of trees in the stand decreasing over time. Relational magnitudes are checked next. For example, a tree (or stand) with a 1-inch diameter growth and 100-foot height growth over a 10-year period would be suspect. Relational sensitivity is checked by changing model control variables and comparing outputs for a given test data set. This whole process may be repeated for several test data sets until the model developers are satisfied with model behavior and confident in the mathematical relationships.

The second step is a limited application test. This step involves the model developers and a few selected users. These users run the model on their own data sets and provide feedback to the developers about model behavior, functional relationships, improvements, refinements, and general applicability and use. Modeling errors are commonly discovered at this point, and many valuable suggestions for model improvements surface.

Once a model is ready to be released for general use, training sessions are held. Training is done at two levels. Managers are given a general training course lasting 1 to 2 days. Course content includes a model overview; gross relationships; types of output expected; strengths, weaknesses, and limitations of the model; and the range of model applicability. Potential users should be given a week of technical training. This course covers specific relationships, model theory, model control variables, output interpretation, and strengths, weaknesses, and limitations of the model, along with a hands-on session to run the model.

Another form of training takes place after a model becomes established. Special seminars covering a specific application of the model can be given in connection with other meetings. This broadens the model's area of use and introduces the model to additional potential users.

Model Maintenance

Maintenance of a modeling system involves changing the computer code in response to some need or correction, keeping users informed of these changes, linking the model to auxiliary routines, and, in some cases, maintaining auxiliary routines. The importance of this job and the amount of time and resources required to do it correctly are frequently underestimated. Individual changes may take from a few minutes to several weeks, and all changes need to be fully documented.

Most changes are requested by the model users. Typically, these are changes in the output table to print out additional information or parameter or requests for additional features and links to auxiliary routines. Model errors are usually discovered by users, who occasionally request changes in the way values are calculated.

Changes can also be requested by the model developers. These changes are usually technical changes such as correcting errors, implementing new methodology in the mathematical relationships, or upgrading the model to a more efficient or expanded level.

Regardless of who sponsors the change, managers and users must be kept informed of the model's status. For managers, the length of time betwee implementing the change and informing them of th change is usually not critical. In these cases, a formal letter documentation is the best.

Users, on the other hand, should be informed as soon as possible of a change. For them, some sort of bulletin system that prints every time the model is used is best. The information is thus available immediately, and every user is informed. Figure 4 is an example of the bulleti system used for PROGNOSIS.

Linking the model to auxiliary routines is often an overlooked part of model maintenance. Auxiliary routines fall into two categories, preprocessors and postprocessors. Preprocessors range from data manipulation routines which put input data into the proper format to interactive

```
XQT TMYIELD*PROGNOSISSCO.PMOD
                                   *****************************************************************
                                   *                                                               *
                                   ********  BULLETIN CONCERNING THIS VARIANT OF PRUGNOSIS  ********
                                   *                                                               *
                                   *****************************************************************

********** ON APRIL 5, 1985 THE SUBMITTAL SYSTEM OPTIONS OF STANDTAB AND SCATTER
        WERE CORRECTED.  THEY SHOULD BOTH WORK CORRECTLY FOR LEVEL 4.0 AND 5.0 VARIANTS
         THE SUBMITTAL SYSTEM KEYWORD  SCATTER  WILL NOW PRODUCE BOTH SCATTERGRAMS AND DIAMETER
        FREQUENCY TABLES FOR THE CYCLES REQUESTED

********** ON MARCH 19, 1985 THE TREELIST KEYWORD FORMAT WAS CHANGED.
        THE NEW FORMAT IS AS FOLLOWS:
        FIELD 1-- DATE/CYCLE NUMBER
        FIELD 2-- DATE/CYCLE NUMBER
        FIELD 3-- DATE/CYCLE NUMBER
        FIELD 4-- DATE/CYCLE NUMBER
        FIELD 5-- DATE/CYCLE NUMBER
        FIELD 6-- DATA SET REFERENCE NUMBER
        FIELD 7-- HEADING SUPPRESSION CODE

****** ON APRIL 30, 1985 SUBROUTINE MORTS WAS CHANGEDTO REFLECT NEW MAXIMUM SDI VALUES OF
         SPECIES      MAX SDI   .85 LEVEL    REFERENCE
         SRF           1207       1027        SCHUMACHER 1928
         WF            1004        854        SCHUMACHER 1926
         SP,IC,ES       881        749        DUNNING & REINEKE
         WP             763        649        HAIG 1932
         MH             758        644
         DF             737        627        SCHUMACHER 1930
         PP             685        583        MEYERS 1938
         J              616        524
         LP             413        352        DAHMS 1964

ON APRIL 30, 1985 SUBROUTINE MORTS WAS CHANGED YOU MAY
        NOTICE A DECREASE IN MORTALITY RATES IN EARLY-MID PROJECTION YEARS


        IF YOU WANT FURTHER INFORMATION ABOUT THESE CHANGES, OR IF THESE CHANGES CAUSE YOUR RUN TO ERROR  --
        PLEASE CONTACT GARY DIXON (WOTM, FT. COLLINS) AT FTS 323-1814 OR COMMERCIAL (303) 224-1814.  THANK YOU.
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igure 4.--Sample computer information bulletin for PROGNOSIS system used on the Fort Collins computer.

rograms that build runstream files necessary to un the model. Postprocessors range from outines which further analyze model output to nes which store model outputs on permanent iles. These auxiliary routines must also be aintained and upgraded to accommodate changes to ne model.

ser Support

or large systems, user support is as important s model maintenance. There are three basic nterrelated categories of user support: (1) roviding assistance in using the model and uxiliary routines, (2) providing assistance in rror tracking and problem solving, and (3) nswering users' questions concerning model pplications.

roviding assistance in using the model and uxiliary routines is the "how to" category. his includes training sessions covering model sage, helping users with computer control anguage commands, answering questions concerning ata preparation and model control commands, nterpreting output, and debugging runstreams.

ne second category is the "help!" category. hen errors are discovered or problems arise when unning the model, they must be traced through ne program to find the cause. Then the errors ust be corrected, and the users should be otified. Often problems are caused by users' mistakes or by extending the model relationships beyond their intended bounds. Adequate training can help minimize these difficulties.

The third category is the "what if" category. It includes questions such as: What happens if the model is used outside its intended geographic range? What happens to the model relationships if the user is missing a variable on the input data? Which variant can I use for the Bitterroot National Forest? And a host of other questions.

Documentation

Proper documentation is an important part of maintaining any system, especially if a model has several geographic variants. It is often difficult to remember what change was made, when it was made, and to what variants it applied. Proper documentation is necessary to answer technical questions, resolve challenges to procedures that were used, and allow other programmers to follow what was done.

Several forms of documentation are important. Comment statements in the computer code are useful to programmers and some users and represent a minimum level of documentation. A central file outlining code changes should also be maintained. For programmers and nonprogrammers, this provides a quick and easy way to resolve questions. Backup copies of the model should also be maintained for future

reference and use. Sometimes an old version of a model must be used to reproduce a given output, analyze an alternate management strategy consistent with already established results, or to respond to legal inquires. Also, files containing the model may be damaged or lost from the computer system. Without proper documentation, resolving these problems would be almost impossible.

Planning for System Review and Evaluation

Sometimes when a model is developed or extended into a new geographic range, some relationships are weak because of a lack of data. Other times, after a period of use it becomes apparent that the model just is not operating the way it should or that some enhancements would make it more useful. These cases point out the need for a careful system review and model evaluation once a model is in use. These reviews can help direct new research to strengthen weak relationships or correct errors and inconsistencies. Naturally, some system review and evaluation comes just from feedback as the model is used; however, planning for a formal review and evaluation can improve most models.

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RMYLD UPDATE: NEW GROWTH AND YIELD RELATIONSHIPS FOR ASPEN

Carleton B. Edminster and H. Todd Mowrer

\BSTRACT: Whole stand growth and yield relation- hips have been developed for even-aged stands of spen in the central Rocky Mountains and incor- orated into a new species-specific subroutine of he RMYLD model. Potential production is esti- ated for various combinations of site quality, otation age, and initial thinning intensities. lerchantable cubic-foot volume is maximized at elatively high stand densities. Early precom- ercial thinning produces fewer but larger trees t rotation with relatively small decreases in otal yield compared to unthinned stands.

NTRODUCTION

here are 3.78 million acres of commercial aspen Populus tremuloides) forest in Colorado, Utah, nd Wyoming (Green and Van Hooser 1983). More han 75 percent is in Colorado. The net bole olume of aspen growing stock in these three tates was more than 3.25 billion cubic feet in 977.

he potential of aspen for wood production and anagement has been relatively neglected. In ecent years the wide distribution of aspen, oncerns for timber supplies and stand condi- ions, and improved utilization have increased nterest in its growth and yield characteristics nd management potential (USDA Forest Service 976). Baker (1925) studied the growth and yield f aspen in central Utah and felt his results ould be generally applicable throughout the entral Rocky Mountains; however, his yield ables are limited to narrow ranges of stand ensity and geographic distribution of growth lots. Although estimates of future growth and ield of aspen have been made by reference to hese early tables or by reference to stock ables of similar stands, both methods have erious limitations. The early yield tables are ot representative of a wide variety of stand ensities, and the use of stock tables is limited the accuracy of expectations about future onditions of the subject stand.

aper presented at: Growth and Yield and Other ensurational Tricks: A Regional Technical onference, Logan, UT, November 6-7, 1984.

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MODEL DEVELOPMENT

Silvical characteristics of aspen make it an ideal species for a whole stand, even-aged growth and yield model such as RMYLD (Edminster 1978). In 1979 in cooperation with Colorado State University, a study was begun to collect growth data and develop whole stand growth and yield relationships for aspen stands in Colorado, southern Wyoming, and northeastern Utah. Data were collected from 101 temporary plots located in single, even-aged clones. The clones were purposively selected to represent a wide variety of stand conditions (table 1).

Table 1.--Summary of stand conditions sampled in the aspen growth study

Characteristic	Mean	Minimum	Maximum
Site index (feet)	63.3	29.0	111.0
Average age at b.h. (years)	68.6	17.0	131.0
Trees per acre	1,088.0	128.0	5,469.0
Basal area per acre (ft^2)	160.5	12.0	351.0
Average diameter (inches)[1]	6.6	1.6	15.0
Average dominant and codominant height (feet)	48.6	14.8	100.7
Total volume per acre (ft^3)	3,551.4	97.2	12,879.2
Merchantable volume per acre (ft^2)[2]	4,498.0	187.2	12,311.6
Sawtimber volume per acre (board feet)[3]	22,724.1	2,238.0	61,031.0

[1]Average diameter is the diameter of the tree of average basal area.
[2]Values for merchantable volume based on 57 plots with average diameter 5.0 inches and larger. Merchantable volume computed for trees 5.0 inches d.b.h. and larger to a 4-inch top.
[3]Values for sawtimber volume based on 36 plots with average diameter 7.0 inches and larger. Sawtimber volume computed for trees 7.0 inches d.b.h. and larger to a 6-inch top.

Relationships to project average stand diameter, average dominant and codominant height, and periodic stand basal area growth were developed,

as were relationships to estimate changes in average tree characteristics and numbers of trees per acre due to thinning from below to various levels (Edminster and Mowrer in preparation). Stand volume equations are used to compute total and merchantable cubic-foot and board-foot volumes per acre. These relationships were incorporated into a new species-specific subroutine for RMYLD. Growth and yield estimates contained in this paper are based on these relationships.

STAND CONDITIONS SIMULATED

Yield simulations were made for the following range of initial stand conditions and management controls:

1. Site indexes at 80 years of age at breast height (b.h.) are 40, 50, 60, 70, 80, and 90 ft. (Edminster and others 1985).
2. Average b.h. is 20 years.
3. Average stand diameter (d.b.h.) is related to site index as follows (average stand diameter is the diameter of the tree of average basal area):

Site index (ft)	Initial d.b.h. (in)
40	2.0
50	2.2
60	2.4
70	2.6
80	2.8
90	3.0

4. Stand density is 2,000 trees per acre.
5. No catastrophic mortality occurs during the rotation.
6. Single precommercial thinnings are made at b.h. age 20 to growing stock levels 80, 100, 120, 140, 160, and 180. (Growing stock level [GSL] is defined as the residual square feet of basal area when average stand diameter is 10 inches or more. Basal area retained in a stand with an average diameter of less than 10 inches is less than the designated level [Edminster 1978]). Stands are also left unthinned for the rotation.
7. Maximum rotation age at b.h. is 120 years, with a clearcut regeneration method.
8. Minimum size for inclusion in merchantable cubic volume is 5.0 inches d.b.h. to a 4-inch top.

The precommercial thinnings produced a range of numbers of trees retained, depending on GSL and site index as shown in the following tabluation:

Site index (ft)	Trees per acre retained after precommercial thinning	
	GSL 80	GSL 180
40	515	1,198
50	494	1,159
60	473	1,116
70	452	1,073
80	432	1,030
90	413	988

Only precommercial thinnings were examined due to increased incidence of decay and mortality in partially cut pole-sized stands (Walters and others 1982). In addition, partial cutting results in inferior replacement stands (Jones 1976); therefore, only regeneration by clearcutting is considered.

MODEL RESULTS AND DISCUSSION

Diameter Growth

Periodic diameter growth of aspen is related to stand density, as represented by stand basal area and site quality. Ten-year periodic diameter growth averaged 0.7 inch for all stands sampled in the growth study. At low site indexes, periodic diameter growth averaged 0.6 inch, and at high site indexes the growth rate averaged 0.8 inch. Periodic diameter growth is a linear function of site index, but the effect of site index appears to be much less than for conifers in even-aged stands in the central Rocky Mountains. As with most species that are suited to even-aged management, diameter growth of aspe is greatest at low stand densities, but these lo stand densities result in reduced volume yields per unit area. Determination of desirable stand density for managed stands involves consideratio of both average tree size and volume production. To achieve appreciable increases in diameter growth, stand basal area must be reduced below 100 ft²/acre.

Periodic growth rates and changes in diameter resulting from precommercial thinning were examined to determine average tree sizes relativ to rotation age and initial stand density. For the range of stand densities and site indexes examined, trees reach average diameters of 5.7 t 9.0 inches at 80 years, and 8.1 to 12.3 inches a 120 years (table 2). On lands of moderately goo site index 70, average stand diameters reach 5 inches at 37 to 54 years of age, 7 inches at 64 to 83 years, and 9 inches at 91 to 111 years (fig. 1). Average diameters ranged from 9.6 to 11.3 inches at the maximum rotation age tested, which was 120 years on site index 70 lands. Th number of decades required to reach an average stand diameter of at least 5.0 inches for computation of merchantable cubic volume ranged from on thinned site index 90 lands to 7 on unthinne site index 40 to 60 lands (table 3).

Height Growth

Periodic height growth of aspen increases with site index and decreases with age and stand density. Average dominant and codominant heigh growth follows the site index curves (Edminster and others 1985) with adjustments downward to account for average codominant as well as dominant height (fig. 2). Differences in average dominant and codominant height due to initial stand densities tested are relatively minor. T maximum difference between stands initially thi ned to GSL 80 and unthinned stands was 3 ft at 120 years of age across the range of site indexes.

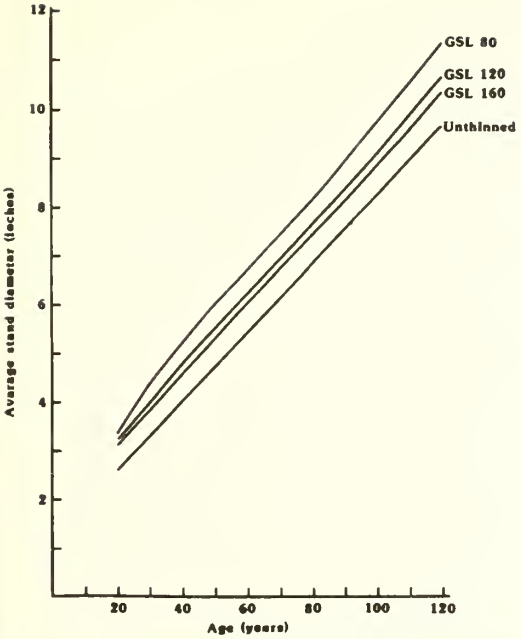

Figure 1.--Estimated average stand diameter of aspen in relation to age and initial stand density on site index 70 lands.

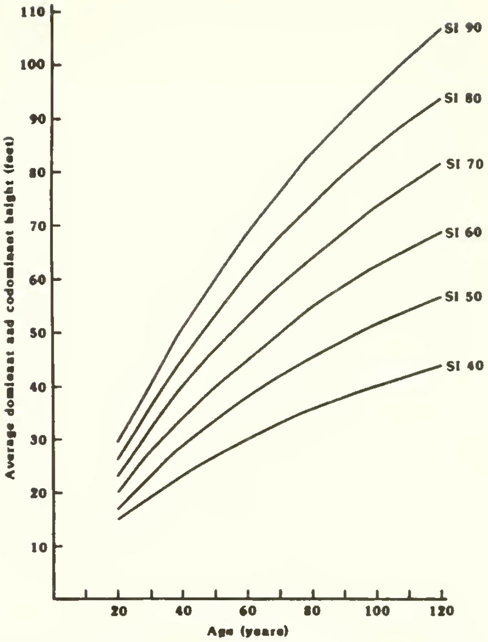

Figure 2.--Estimated average dominant and codominant height of aspen in relation to age and site index.

Table 2.--Estimated average stand diameter (in) and number of trees per acre of aspen at final harvest in relation to initial stand density, site quality, and rotation age

	Growing stock level													
	80		100		120		140		160		180		Unthinned	
Rotation age	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees	Diameter	No. of trees
							Site Index 40							
60	5.9	410	5.6	479	5.4	553	5.2	617	5.1	655	5.0	704	4.5	923
80	7.3	333	7.0	381	6.6	450	6.4	496	6.3	517	6.2	553	5.7	688
100	8.7	271	8.4	304	7.9	361	7.6	399	7.5	417	7.4	438	6.9	527
120	10.1	222	9.8	246	9.3	284	9.0	312	8.9	321	8.7	343	8.1	416
							Site Index 50							
60	6.1	428	5.8	501	5.7	553	5.6	608	5.4	660	5.2	745	4.7	987
80	7.5	358	7.2	406	7.1	443	7.0	478	6.7	530	6.4	599	5.9	758
100	8.9	300	8.6	334	8.5	357	8.4	381	8.1	416	7.7	473	7.1	592
120	10.3	250	10.0	275	9.9	291	9.8	307	9.5	333	9.1	371	8.4	462
							Site Index 60							
60	6.3	429	6.1	497	5.9	563	5.8	615	5.8	648	5.6	713	4.9	1046
80	7.7	371	7.5	417	7.3	464	7.2	498	7.2	519	7.0	561	6.1	813
100	9.1	316	8.9	349	8.7	382	8.6	406	8.6	423	8.4	446	7.5	612
120	10.6	264	10.3	293	10.1	316	10.0	335	10.0	346	9.8	364	8.9	476
							Site Index 70							
60	6.7	412	6.4	496	6.2	553	6.1	620	6.0	667	5.9	721	5.4	974
80	8.1	366	7.8	424	7.6	463	7.5	508	7.4	542	7.3	578	6.8	741
100	9.7	307	9.2	363	9.0	391	8.9	423	8.8	445	8.7	472	8.2	583
120	11.3	258	10.8	298	10.6	318	10.4	347	10.3	362	10.1	388	9.6	467
							Site Index 80							
60	7.0	396	6.8	467	6.5	546	6.4	599	6.2	672	6.2	701	5.6	1011
80	8.6	342	8.4	389	8.0	452	7.8	503	7.6	552	7.6	574	7.0	785
100	10.2	297	10.0	330	9.6	376	9.4	410	9.1	453	9.1	469	8.4	623
120	11.8	255	11.6	279	11.2	312	11.0	337	10.7	368	10.7	379	9.9	493
							Site Index 90							
60	7.4	388	7.1	458	7.0	508	6.8	563	6.8	610	6.4	707	5.8	1051
80	9.0	339	8.7	387	8.6	423	8.4	459	8.4	493	8.0	555	7.2	820
100	10.6	300	10.3	355	10.2	361	10.0	386	10.0	410	9.6	455	8.7	645
120	12.3	259	11.9	288	11.8	308	11.6	327	11.6	343	11.2	375	10.3	508

Table 3.--Estimated number of decades to reach an average stand diameter of at least 5.0 inches in relation to initial stand density and site index

Site Index	Growing stock level 80	100	120	140	160	180	Unthinned
40	5	6	6	6	6	6	7
50	5	5	5	6	6	6	7
60	5	5	5	5	5	6	7
70	4	4	5	5	5	5	6
80	4	4	4	4	5	5	6
90	4	4	4	4	4	4	5

Basal Area Increment

Periodic basal area increment increases with site index and decreases with increasing stand age. For a given site index and stand age, periodic basal area increment is relatively constant for stand ages greater than 40 years over the range of initial stand densities tested. This suggests that basal area growth at the lower stand densities was not redistributed on the fewer residual stems. The pattern of basal area development in relation to age and site index for unthinned stands is shown in figure 3. At a stand age of 120 years, basal area production per acre varied from 149 ft² on site index 40 lands to 294 ft² on site index 90 lands.

Basal area growth relationships in the model predict growth based on estimated 10-year periodic plot performance. Since mortality is often a clustered event, in both location and time,

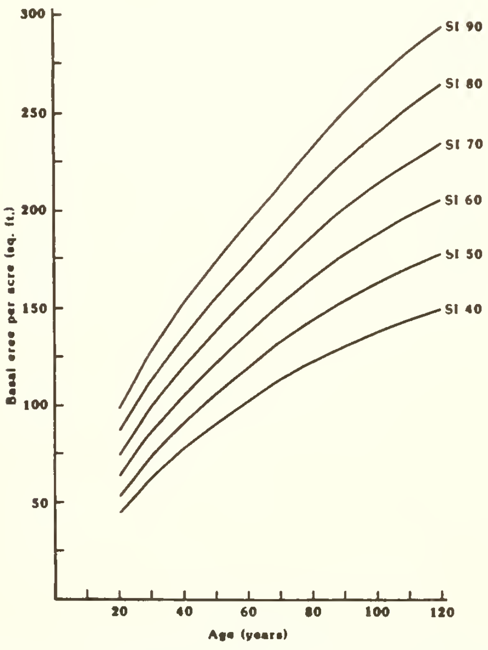

Figure 3.--Estimated stand basal area development in unthinned stands of aspen in relation to age and site index.

samples from a relatively small number of stands over a short time period may not be adequate to accurately predict long-term mortality rates. Further complications arise from the clonal growth and self-thinning characteristics of aspen (Zahner and Crawford 1965). As a result, the prediction of mortality is the weakest component in the aspen growth model.

Merchantable Cubic-Foot Volume Increment

Gross merchantable cubic-foot volume production of aspen is related to stand density, site quality, and rotation age (table 4, fig. 4). Merchantable cubic-foot production was greatest for all site indexes, except site index 40, in unthinned stands. This follows a similar trend for basal area production. The differences in merchantable volume production for a given initial stand density become greater with increasing site index. Although merchantable volume production decreases with reduced GSL's or moderate to high site index lands, tree sizes at higher densities are smaller, and considerably more trees must be harvested to obtain the higher stand volumes (tables 2 and 4). For example on site index 70 land at 120 years of age, unthinned stands produce 6.5 percent more merchantable volume than stands initially thinned to GSL 180, but the unthinned stand contains 20.4 percent more trees which are 0.5 inch smaller in average diameter.

Compared to earlier estimates for aspen in central Utah (Baker 1925), predicted merchantable yields from this study are considerably higher, with differences increasing with increasing site quality. Although direct comparisons are not possible due to different site curves used to index productivity, the following approximate comparisons at stand age 120 years for unthinned stands on a per-acre basis can be made:

Baker Site Class (index height)	Merchantable cubic-foot yield: Baker	Current study
1 (77)	4,600	8,680
2 (67)	3,400	6,540
3 (55)	2,300	4,520
4 (44)	1,700	2,740

Only a small portion of the difference can be explained by the larger utilization standards in Baker's study, where cordwood cubic-foot volume was calculated for trees 6.0 inches d.b.h. and larger to a 5-inch top.

Mean annual increment (MAI) of merchantable cubic-foot volume provides an objective criteric for evaluting growth consequences of different precommercial thinning levels and unthinned stands (Assman 1970). Gross merchantable cubic-volume MAI is related to age, site quality, and initial stand density (fig. 5). For each initia stand density, merchantable cubic-foot volume MA is greater at each higher site index, and differences become greater with increasing site index. Mean annual increments are increasing through stand age of 120 years. Site indexes 50 and

Table 4.--Estimated gross merchantable cubic-foot volume production per acre of aspen in relation to initial stand density, site quality, and rotation age (trees 5.0 inches d.b.h. and larger to a 4-inch top)

Rotation age	Growing stock level						
	80	100	120	140	160	180	Unthinned
Years	Thousand cubic feet						
			Site Index 40				
60	0.63	0.61	0.61	0.58	0.56	0.55	0.00[1]
80	1.16	1.17	1.18	1.18	1.17	1.18	1.12
100	1.65	1.68	1.71	1.71	1.71	1.74	1.72
120	2.09	2.13	2.18	2.20	2.19	2.22	2.23
			Site Index 50				
60	1.01	1.00	1.04	1.06	1.03	1.01	0
80	1.76	1.79	1.86	1.92	1.90	1.91	1.91
100	2.50	2.55	2.64	2.72	2.72	2.74	2.80
120	3.17	3.24	3.34	3.42	3.44	3.48	3.57
			Site Index 60				
60	1.39	1.45	1.50	1.55	1.62	1.60	0
80	2.39	2.51	2.59	2.69	2.79	2.79	2.86
100	3.41	3.56	3.67	3.79	3.92	3.93	4.12
120	4.36	4.53	4.66	4.80	4.93	4.95	5.21
			Site Index 70				
60	1.86	1.98	2.02	2.16	2.21	2.28	2.39
80	3.14	3.32	3.40	3.61	3.70	3.82	4.10
100	4.49	4.71	4.81	5.07	5.18	5.33	5.72
120	5.79	6.04	6.15	6.42	6.56	6.72	7.16
			Site Index 80				
60	2.32	2.52	2.64	2.77	2.86	2.98	3.27
80	3.89	4.16	4.35	4.53	4.69	4.85	5.42
100	5.58	5.91	6.15	6.41	6.58	6.78	7.50
120	7.05	7.44	7.78	8.11	8.34	8.57	9.38
			Site Index 90				
60	2.92	3.11	3.34	3.43	3.70	3.71	4.29
80	4.83	5.09	5.40	5.55	5.92	5.99	6.93
100	6.93	7.25	7.62	7.81	8.27	8.38	9.56
120	8.62	9.01	9.42	9.66	10.14	10.37	11.92

[1]Stand merchantable cubic-foot volume is not computed when average stand d.b.h. is less than 5.0 inches.

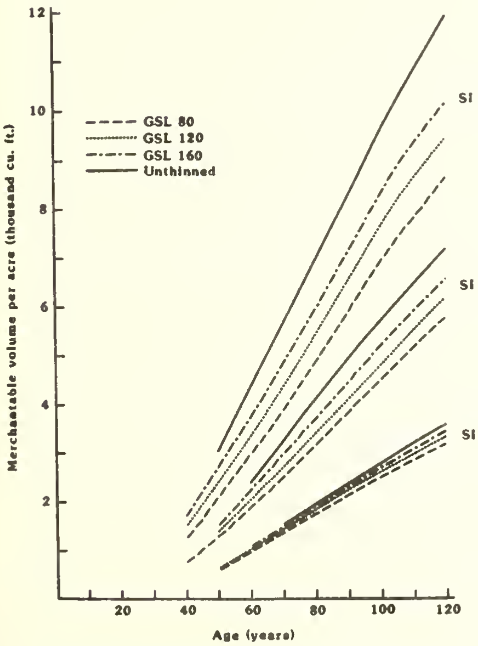

Figure 4.--Estimated gross merchantable cubic-foot volume production per acre of aspen in relation to age, initial stand density, and site index.

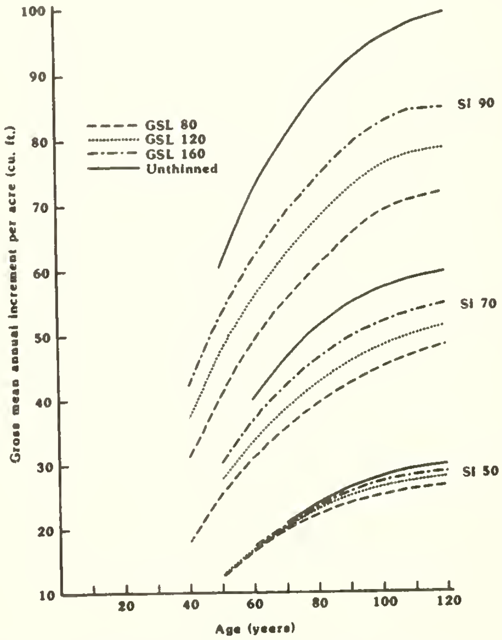

Figure 5.--Estimated gross mean annual merchantable cubic-foot volume increment per acre in relation to age, initial stand density, and site index.

above produce more than 20 ft³/acre annually. Mean annual increment in unthinned stands on site index 90 lands approaches 100 ft³/acre.

A pathological rotation of 90 to 120 years for sawtimber production of aspen in Colorado has been suggested by Hinds and Wengert (1977). Deductions in cubic-foot volume for decay (Davidson and others 1959) were applied to the gross MAI values in figure 5 to determine a reasonable rotation for merchantable cubic-foot volume. Results of the decay study were based on Baker's site classification, and application of the results to the current study is an approximation. Decay deductions for site class 1 were applied to site indexes 80 and 90, class 2 to site index 70, and class 3 to site index 60 and below. Estimates of net merchantable cubic-foot volume MAI's are shown in figure 6. Culmination of net MAI generally occurs between 100 and 120 years, most often at 100 years of age. These results support the recommendations for sawtimber production. Cull resulting from decay varies greatly in stands of comparable age and site quality (Davidson and others 1959; Hinds and Wengert 1977). As a result, the estimates reported here should only be applied to a specific stand with care.

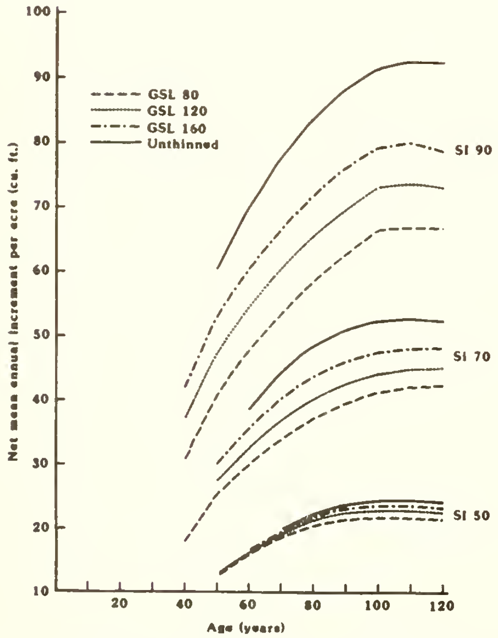

Figure 6.--Estimated net mean annual merchantable cubic-foot volume increment per acre in relation to age, initial stand density, and site index.

MANAGEMENT CAUTION

The growth and yield estimates presented appear reasonable and consistent within the limits of current knowledge based on sampling even-aged natural stands of aspen at a wide variety of stand age, density, and site quality. Comparisons of estimates with actual values from permanent plots in managed and unthinned stands are needed to validate growth relationships and estimates. Thinning studies in a pole-size stand and juvenile stands on three site quality lands are currently underway to provide some of this information.

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INTRODUCTION TO THE PROGNOSIS MODEL--VERSION 5.0

William R. Wykoff

ABSTRACT: The Prognosis Model is a stand development simulator that facilitates forest management planning. Stand development is simulated by predicting the growth of sample trees from an inventory. The stand is assumed to be homogeneous with regard to distributions of species, age classes, site factors, and treatment potential. The model is intended to accommodate all timber types and stand conditions that are encountered in an inventory with growth predictions that are consistent with measured growth. Model versions 4.1 and 5.0 are compared. Version 5.0 outperforms version 4.1 with regard to the permanent sample plots used to assess model validity; in addition, its calibration procedure increases the accuracy of projections and does not depend on growth sampling strategies. Long-range projections of total volume appear to be unbiased, and the model should be useful for long-range planning.

WHAT IS THE PROGNOSIS MODEL?

The Prognosis Model (Stage 1973) is a stand development simulator that facilitates forest management planning. The design of the model was based on five objectives (Wykoff and others 1982):

1. Use existing inventory data as input and produce initial estimates of volume and growth that are consistent with results of standard inventory compilation procedures.

2. Accommodate all timber types and stand conditions that are encountered in the inventory with growth predictions that are consistent with measured growth.

3. Treat stands as the basic unit of management.

4. Incorporate growth of the current inventory into projections.

5. Provide links to other biotic and hydrologic components of the ecosystem and to econometric procedures for selecting appropriate management actions.

The resulting model simulates stand development by predicting growth, mortality, and the impact of management activities for a sample of trees that comprise the stand. The concept is simple: a list of trees is projected forward in time with sufficient descriptive detail to support decisions that are traditionally based on inventory.

The current formulation of the model, as calibrated for the Inland Empire, predicts d.b.h. increment, height increment, survival, and change in crown length for individual trees for variable length periods. There are also linkages to interactive population dynamic models for specific pests that can modify the predicted growth and survival or the perceived vigor of the trees. At the end of a growth prediction cycle (usually 10 years), tree volumes are computed, stand density and yield statistics are compiled, scheduled management activities are simulated, and a new cycle begins.

Although the conceptual framework outlined above is simple, the Prognosis Model is admittedly complex. The Inland Empire has a relatively rich species diversity, considerable geographic relief, and a history of recurrent insect and disease problems, catastrophic fires, and less-than-enlightened management. A simple model would be inadequate to address the spectrum of current management problems in the context of this diversity; however, the model was designed to minimize the impact of complexity on the user. Management actions are specified with relatively straightforward keywords, and the output includes displays of stand development that vary in resolution from a yield table to a complete list of the attributes of all trees in the stand. The first production version of the Prognosis Model, version 4.0, was released in 1981; version 4.1 was subsequently released with changes to the small-tree growth models; version 5.0 was released in the summer of 1984. The options described in the user's manual for version 4.0 (Wykoff and others 1982) are applicable to version 5.0, and new options are specified in a supplement to the user's guide (Wykoff in preparation). This paper briefly describes and contrasts the function and behavior of versions 4.1 and 5.0.

WHAT MANAGEMENT ACTIVITIES MAY BE SIMULATED?

In version 4.1, management options are limited to activities that reduce stocking of existing stands (Wykoff and others 1982). A great deal of flexibility is permitted in determining the trees to be removed, and the growth response varies

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with the character of the residual stand. For most thinning options, the date of an entry must be specified by the user.

These same features have been included in version 5.0. In addition, an Event Monitor (Crookston in preparation) may be used to schedule activities contingent on stand characteristics rather than date. As a simple example, a stand may be automatically thinned to 100 ft^2 of basal area any time that the stand density exceeds 140 ft^2. In fact, the event that triggers an activity can be defined to simultaneously include specified values for many stand characteristics so that complex strategies can be simulated.

Along with the Event Monitor, a new biological model has been added to version 5.0 to predict the establishment of regeneration following site disturbance. This addition permits the evaluation of reforestation strategies (Ferguson and Crookston 1984). It may also be used to include the influence of ingrowth competition following thinning.

Versions 4.1 and 5.0 are both programmed to link readily to "extensions" that simulate the dynamics of specific pest populations and their impact on the stand. At present, a tussock moth model is available (Monserud and Crookston 1982), and western spruce budworm and mountain pine beetle models are under development. These extensions can be used to test the impact of control strategies on the development of the stand and of the pest population. In addition, the program for computerized help for economic analysis of Prognosis output, CHEAPO (Medema and Hatch 1982), has been revised and rereleased for version 5.0.

Also under development is a model that predicts the distribution of shrub species and the percentage of cover (including shrubs and trees) by vertical strata within the stand (Moeur in preparation). This extension facilitates linkage to models that predict wildlife populations or water production from the estimates of forage availability and cover density.

Finally, there are two algorithms under development that will further enhance the flexibility of version 5.0. The first is an uneven-aged management algorithm that, in conjunction with the Regeneration Establishment Model, permits simulation of all-age management strategies (Lyons in preparation). The second is the Parallel Processing System, which can project up to 200 stands simultaneously. With this system, contagious effects of pests can be considered, and harvests can be planned to meet watershed and visual constraints. Also, when used with the Event Monitor, the Parallel Processing System can efficiently simulate a rather complex decision tree (Crookston in preparation).

CHANGES IN GROWTH MODELS

The differences between the growth models in versions 4.1 and 5.0 reflect an attempt to make the individual tree projections more sensitive to differences in stand structure. The most important changes are in models that predict height and d.b.h. increments and changes in crown ratio for small trees (d.b.h. $\leq$3 inches) and mortality rates for all trees.

Small-Tree Height and Diameter Increment

In version 4.1, diameter increment is predicted with the same model for all trees, and there is no feedback between the small-tree height increment and d.b.h. increment models. As a result, height and d.b.h. predictions may be inconsistent, resulting occasionally in trees that are extremely tall for their d.b.h.'s. In version 5.0, small-tree diameter increment is predicted directly from height and height increment, thus assuring consistency.

In addition to the inconsistency between height and d.b.h. increment predictions, version 4.1 height increment predictions are not dependent on any measure of the competitive status of a tree relative to its neighbors. Thus, there is little in the model to promote the expression of dominance, and the model does not reproduce the within-stand variation in height and diameter that is typically found in young managed stands. In version 5.0, this problem was mitigated by adding a relative size term to the small-tree height increment model. Predictions of height and d.b.h. increment are, as a result, sensitive to both social status and overall stand density (fig. 1).

Small-Tree Crown Ratio

With the change in strategy for predicting d.b.h. increment, none of the growth predictions for small trees are dependent on crown ratio. Assignment of crown ratio is consequently delayed until the tree attains a 3-inch diameter. Crown ratio is then predicted from species, d.b.h., height, and stand basal area. Thereafter, crown ratio change is predicted as in version 4.1.

Mortality

In version 4.1, a basic mortality rate is predicted from species and d.b.h. The basic rate is then adjusted to reflect the effects of stand density. Adjustment factors are based on yield tables (Haig 1932), published data on carrying capacity by habitat type (Pfister and others 1977), analysis of Northern Region timber management planning inventories, and some judicious guessing.

The version 5.0 models are dependent on species, d.b.h., d.b.h. increment, relative diameter (d.b.h./mean stand d.b.h.), and stand basal area (Hamilton in preparation). The explicit density and relative size terms have eliminated the need for most of the guesswork that was included in version 4.1. As stand density increases, mortality rates increase for all trees; the dominant trees and subordinate trees that exhibit rapid growth have the best chance of survival. The new formulation results in reduced mortality rates following stocking reduction or treatments that otherwise enhance the growth of the residual trees.

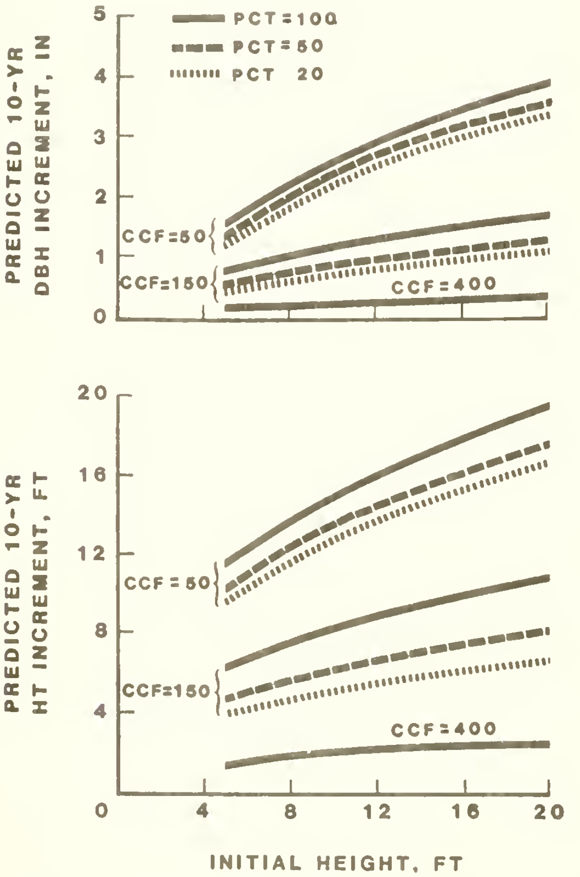

Figure 1.--In version 5.0, small-tree height and diameter increment predictions are sensitive to stand density and relative size. Curves are for Douglas-fir growing on a Thuja plicata/Clintonia uniflora habitat type at 3,700 feet elevation in the Clearwater National Forest.

Large-Tree Diameter Increment

Changes to the large-tree d.b.h. increment model are somewhat more subtle. In version 4.1, the relative size term has about the same effect on the d.b.h. increment prediction regardless of tree size. In version 5.0, a d.b.h.-relative size interaction term was added to decouple the size and relative size effects. Thus, an increment prediction for a small tree in one stand is more strongly affected by relative size than is the prediction for a larger tree in a different stand, even though the two trees are at the same relative position in the d.b.h. distribution within their respective stands. As a result of this change, the maximum in the increment curve, as related to diameter, shifts toward larger d.b.h. with increasing density and decreasing percentile in the stand basal area distribution (fig. 2). The net effect is smaller d.b.h. increment predictions for small trees at high densities.

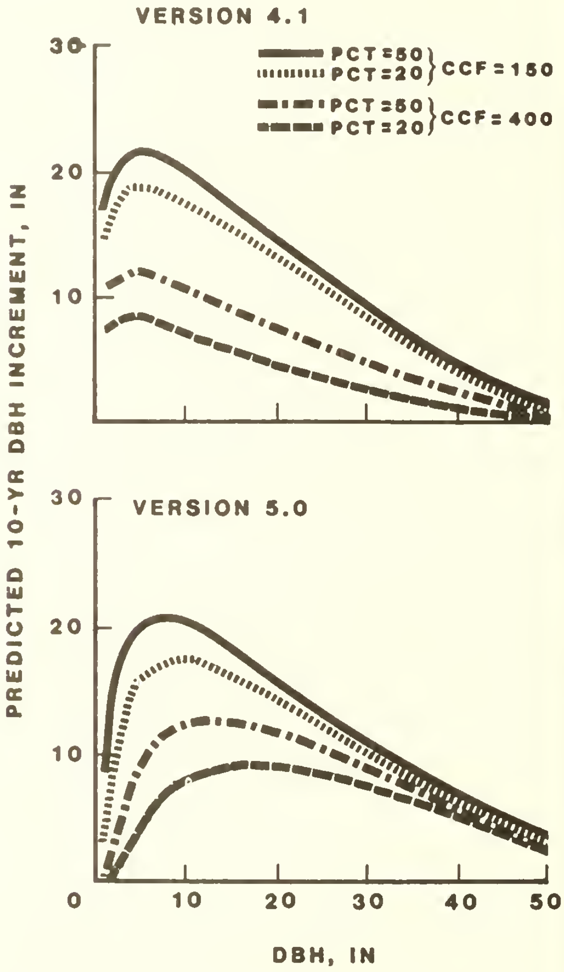

Figure 2.--Large-tree diameter increment models are slightly different in version 5.0. The most notable differences in predictions are for subordinate trees growing in dense stands. In version 5.0, the maxima in the increment curves shifts toward larger d.b.h. as crown competition factor (CCF) increases, and percentile in the stand basal area distribution (PCT) decreases. Stand conditions are the same as for figure 1.

Compression and Calibration

There are two additional modifications to version 5.0 that do not relate specifically to model formulations but do impact performance. First, a regression procedure was adopted to adjust models

for differences between predicted and inventoried growth rates. The Prognosis Model was designed to accommodate considerable variation in the inventory sampling design; however, the version 4.1 calibration procedure only gives unbiased adjustment factors if growth sample trees are selected with probability proportional to tree basal area. The new calibration procedure eliminates bias that results from differences in ways that growth sample trees are selected. The only obvious difference in performance is the requirement for five growth samples for a species in order for the adjustment to take place. This requirement applies to both the large-tree d.b.h. and the small-tree height increment models. In version 4.1, only two growth samples were needed.

The second modification is a compression procedure that permits records to be combined into groups that are similar with regard to variables that strongly influence growth projections. The compression procedure (Stage and others in preparation) is used to create space for new records when the establishment model is called to eliminate records that, due to thinning or mortality, are no longer significant, or to reduce the number of tree records so that projections are less costly but retain as much as is possible of the original variation in tree characteristics.

MODEL PERFORMANCE

A number of "benchmark" simulations were designed to help evaluate model performance. As no standards are available, rigorous analysis of the results of these simulations was not attempted. Comparison of benchmarks, however, illustrates differences between the behavior of versions 4.1 and 5.0 and permits subjective evaluation of model changes.

As discussed earlier, major changes were made in the small-tree height and d.b.h. increment models in version 5.0. The impetus for these changes was the perceived insensitivity of version 4.1 to differences in stand density and structure. In stands of small trees there was insufficient variation in the distribution of within-stand diameters and too little difference in average stand diameter across a wide range of spacings for stands of the same age. With version 5.0, as illustrated by projections for a white pine spacing study (figs. 3 and 4), there is greater spread in the within-stand diameter distribution and wider spacings result in significantly larger average stand diameters.

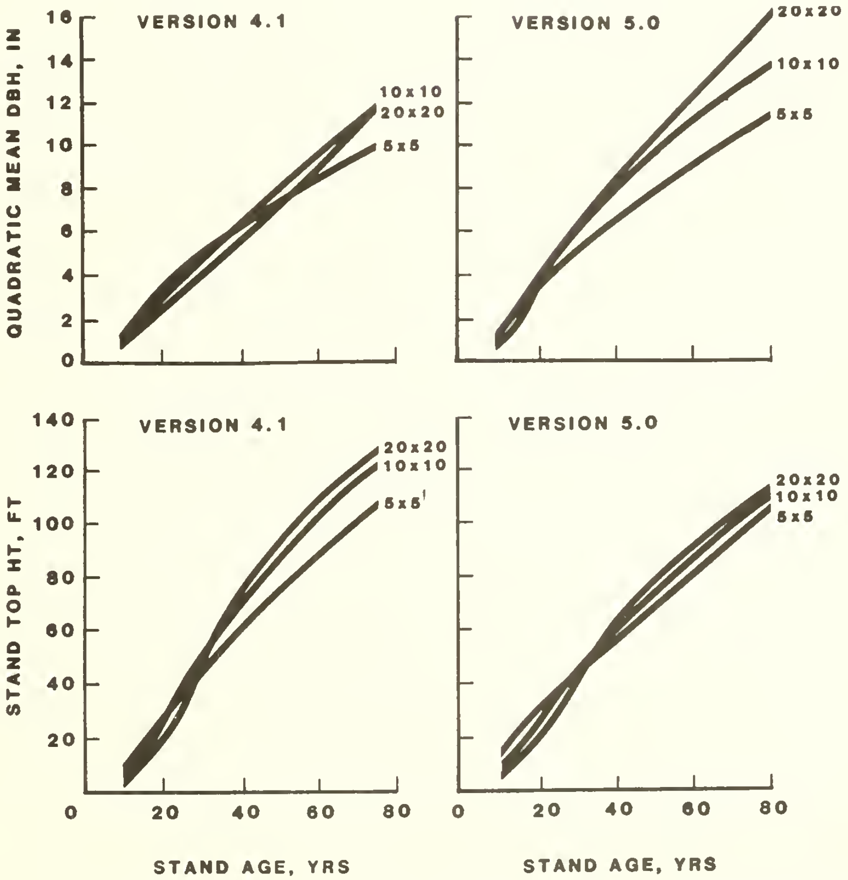

Figure 3.--When projections are made for different initial spacings, version 5.0 produces more variation in quadratic mean d.b.h. and less variation in stand top height than does version 4.1. Curves are for western white pine growing on a Tsuga heterophylla/Clintonia uniflora habitat type at 3,400 feet elevation on the Coeur d'Alene National Forest.

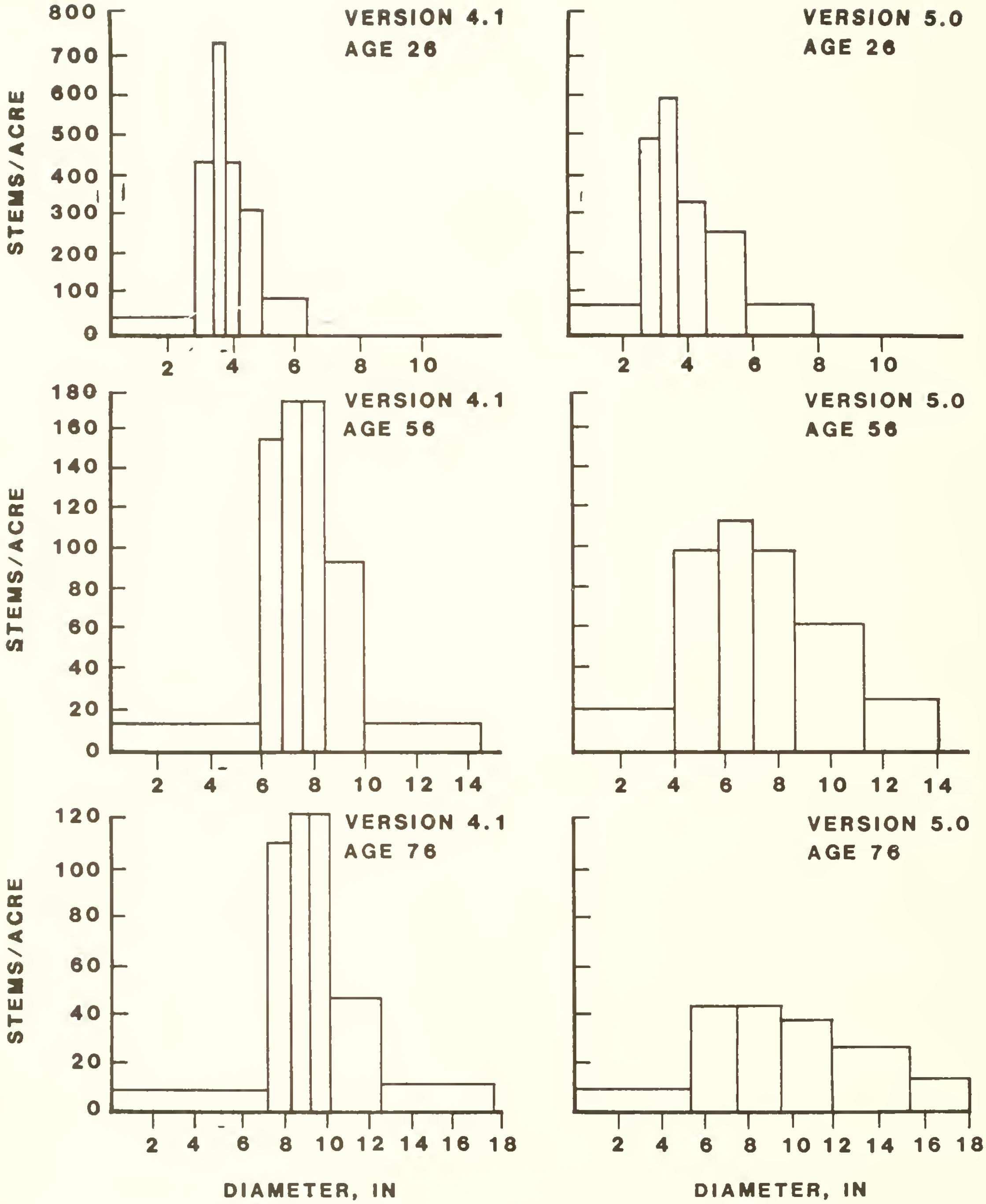

Figure 4.--Version 5.0 projections result in greater variation in within-stand d.b.h. than do version 4.1 projections. Stand conditions are the same as for figure 3. Distributions shown are for the 5- by 5-foot initial spacing.

The changes in the model for small trees improved the discrimination of site quality. When Douglas-fir plantations were simulated with version 4.1 for radically different sites (ranging in quality from a Thuja plicata/Clintonia uniflora habitat type at 3,700 feet elevation in the Clearwater National Forest to an Abies lasiocarpa/Menziesia ferruginea habitat type at 5,200 feet on the Lolo National Forest), there was only a 17-foot difference between top heights at a stand age of 110 years. With version 5.0, this difference increased to 35 feet (fig. 5). Projections with both versions were made without calibrating the growth models to match past growth. Otherwise, the range of apparent site quality could be greater; the use of inventory growth data is an important design feature of the model that helps resolve variation in site quality within a habitat type. Projections based on average growth rates cannot reflect the range of variation in site quality evidenced in nature.

Other benchmark simulations have been designed to exercise various model features such as compression, thinning, and regeneration establishment. These simulations are distributed with the program and will be valuable for user assessment of model performance now and following future changes. As earlier indicated, however, these comparisons do not address model validity.

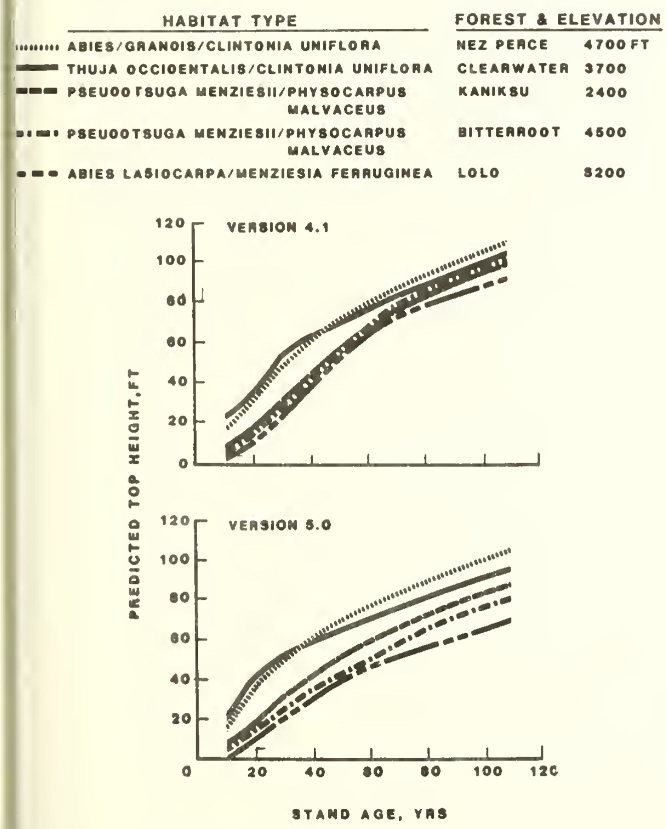

Figure 5.--Comparison of top height projections for versions 4.1 and 5.0 with Douglas-fir planted on a variety of sites. Projections began with a list of tree records that was generated by the Regeneration Establishment Model for the indicated site conditions.

An independent evaluation of model performance and comparison of versions is nearing completion. This comparison is based on a collection of 119 permanent sample plots that are located on relatively productive sites in northern Idaho. The plots have been measured every 5 to 10 years for total periods ranging from 10 to 60 years (mean 34.5 years). In these analyses, errors due to mortality predictions were isolated from errors due to increment predictions by suppressing the mortality function and removing only the trees that actually died at the time they were recorded as dead.

The version 4.1 calibration procedure was among the early casualties of the evaluation. As was earlier described, this calibration procedure was optimized for inventory systems in which trees were sampled for growth in proportion to their basal area. Fixed-area plots were used for the model evaluation and all trees were measured for growth, resulting in an underestimate of model adjustments. Thus, calibrated projections produced poorer estimates of future stand attributes. The calibration procedure was replaced in version 5.0 with a procedure that is more tolerant of differences in growth sampling methods.

Considering the average differences between observed and predicted values for stand attribute in the permanent sample plots, version 5.0 projections of stand attributes are less biased and more precise than predictions from version 4.1 (table 1). In this sense, the version 5.0 formulations represent a substantial improvement.

It is also evident that version 5.0 projections are improved by calibration. The 95 percent confidence intervals constructed about the mean differences between predicted and observed attributes (table 2) show that predictions of total cubic-foot volume are unbiased and that the mean difference between observed and predicted volume is probably less than ±10 percent of the observed change. This level of accuracy is probably sufficient for long-range planning.

Further, when errors attributable to mortality are removed from the analysis, the "no calibration" projections give a good indication of the performance of component growth models. Predictions of quadratic mean d.b.h. are slightly biased, but explain 92 percent of the variation observed in the test data. In this case, explained variation is measured by the ratio of the variance of the bias in predicted change (predicted change minus observed change) to the variance of the observed change. Using this definition, if the average change in stand attributes for the collection of plots were known in advance and used as a model to predict changes, the predictions would be unbiased but none of the observed variation in the system would be explained.

Predictions of top height are unbiased as well and explain 75 percent of the observed variation (tables 2 and 3). Calibration leads to further improvement in explained variation of both attributes, reduces the bias in predicted quadratic

Table 1.--Comparisons of observed change in stand attributes showing bias associated with various estimation procedures[1]

Source of estimate	Stand Attribute: Quadratic mean d.b.h.	Top height[2]	Basal area per acre	Total volume
	Inches	ft	ft²	ft³
Observed change	4.1 (1.98)	32.2 (19.0)	36.6 (52.8)	2,898 (2,031)
Version 4.1, predicted mortality, no calibration	.45 (1.22)	-1.19 (10.5)	66.3 (48.8)	2,369 (2,203)
Version 5.0, predicted mortality, no calibration	.27 (.95)	2.32 (10.2)	31.1 (52.0)	1,140 (2,058)
Version 5.0, predicted mortality, calibration	-.17 (.82)	-2.89 (10.1)	11.0 (43.8)	-17 (1,588)
Version 5.0, observed mortality, no calibration	.28 (.57)	.52 (9.4)	9.71 (21.6)	422 (1,325)
Version 5.0, observed mortality, calibration	.03 (0.44)	-2.87 (9.2)	1.66 (13.6)	-118 (866)

[1]Standard deviation about bias is given in parentheses. Estimates are based on 119 plots with an average measurement period of 34.5 years.

[2]In version 4.1, top height is defined as the average height of the largest 30 percent of the trees in the stand by basal area. In version 5.0, the more traditional definition, height of the largest 40 trees per acre by d.b.h. is used.

Table 2.--Ninety-five percent confidence intervals about the mean error in prediction of change for the stand attributes and estimation procedures shown in table 1

Source of estimate	Stand attribute: Quadratic mean d.b.h.	Top height	Basal area	Total volume
	Inches	ft	ft²	ft³
Version 4.1, predicted mortality, no calibration	(0.23, 0.67)	--[1]	(57.4, 75.2)	(1,967; 2,770)
Version 5.0, predicted mortality, no calibration	(0.10, 0.44)	(0.46, 4.18)	(21.6, 40.6)	(765; 1,515)
Version 5.0, predicted mortality, calibration	(-0.32, -0.02)	(-4.73, -1.05)	(3.0, 19.0)	(-306; 272)
Version 5.0, observed mortality, no calibration	(0.18, 0.38)	(-1.19, 2.23)	(5.79, 13.63)	(181; 662)
Version 5.0, observed mortality, calibration	(-0.05, 0.11)	(-4.55, -1.19)	(-0.82, 4.14)	(-276; 40)

[1]Due to the change in definition for top height, the initial value for comparison with version 4.1 was unknown as of this writing. Consequently, the confidence intervals could not be computed.

Table 3.--Proportion of the total variation[1] in stand attributes for the 119 permanent sample plots that is explained by various estimation procedures

Source of estimate	Variation explained by attribute (Percentage) Quadratic mean d.b.h.	Top height	Basal area per acre	Total volume
	Inches	ft	ft^2	ft^3
Version 4.1, predicted mortality, no calibration	62.0	--[2]	14.6	-17.7
Version 5.0, predicted mortality, no calibration	77.0	71.2	3.0	-2.7
Version 5.0, predicted mortality, calibration	82.8	71.7	31.2	38.9
Version 5.0, observed mortality, no calibration	91.7	75.5	83.3	57.4
Version 5.0, observed mortality, calibration	95.1	76.6	93.4	81.8

[1]Computed as $1 - \dfrac{\text{Variance of bias in predicted change}}{\text{Variance of observed change}} \cdot 100.$

This number is negative when the variance of the bias in predicted change is greater than the variance of the observed change.

[2]Could not be computed--see footnote to table 2.

mean d.b.h., but increases the bias in predicted top height. There is, however, still considerable unexplained variation in the permanent sample plot comparison. It is somewhat disturbing that nearly 50 percent of the predictions were biased by more than 50 ft^3/acre/year (fig. 6), and this apprehension is compounded by the relatively small proportion (39 percent) of variation in total volume that is explained by the model.

There are factors to consider in defense of the model. First, as total length of projection increases, the accuracy of the volume estimates increases (fig. 6). Although we prefer to visualize stand development as a smooth progression relative to time, the processes of growth and mortality are subject to the erratic and intertwined effects of pests, climate, and site. In reality increment and mortality are both clustered in time and space. Errors for short-run projections may be large, but for long-run projections, irregularities average out resulting in more accurate predictions.

Second, when mortality is removed as a source of variation, estimates of future stand attributes substantially improve. It appears that the increment models are sensitive to the diverse stand structures that result from irregular patterns of mortality. We therefore expect the increment models to perform adequately when stand structure is changed through management. Thus, the model should give reasonable predictions of thinning responses.

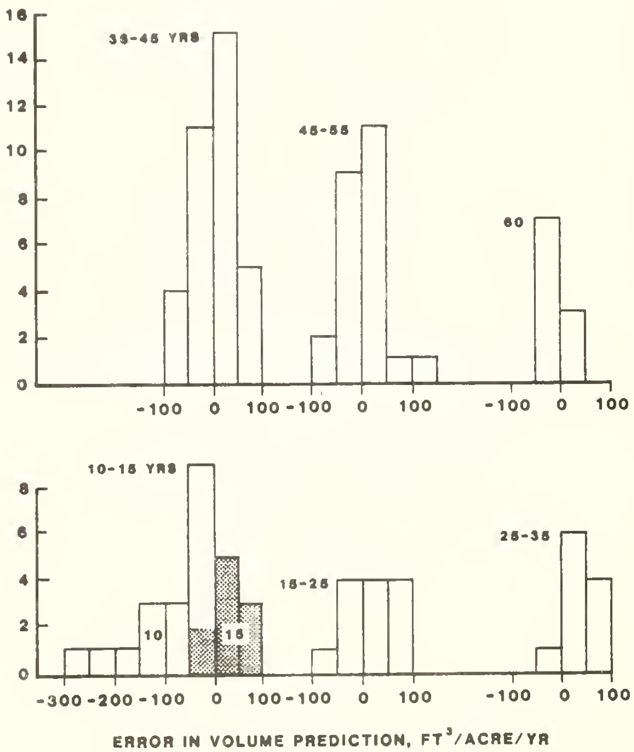

Figure 6.--Distribution of the permanent sample plots used for model evaluation by error in total cubic foot volume predictions and length of projections.

CONCLUSIONS

Version 5.0 outperforms version 4.1 with regard to the permanent sample plots used to assess model validity. In addition, the version 5.0 calibration procedure increases the accuracy of projections and is not dependent on growth sampling strategies.

Long-range projections of total volume appear to be unbiased, and the model should be useful for long-range planning. Growth relations are sensitive to stand structure and density and should give adequate representation of response to management. There remains, however, considerable unexplained variation in mortality.

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DEVELOPING MULTIRESOURCE MODELS FOR

THE LAND MANAGEMENT PLANNING PROCESS

Lawrence D. Garrett

3STRACT: Changes in forest policy and law have laced greater emphasis on multiresource anagement and on techniques to ensure its fficiency and effectiveness. Although lack of ata has impeded progress in multiresource odeling, conceptual and prototype models are eing developed. For the models to find expanded se in land management planning, their development ust be based on sound scientific principles and eflect the needs of management. Managers and nalysts using the models must do so within onstraints specified in their development.

NTRODUCTION

orestry professionals must continue to develop etter methods for managing the productivity and se of the Nation's forest resources. Emphasis is eeded in research, development, and application. ne area requiring additional research effort is odeling multiresource response to alternative anagement strategies (Hartgraves 1981). Better esponse functions are needed to describe an ndividual resource reaction to different alter- atives. But, more important, better systems pproaches are needed at the forest level to roject the interrelated response of several esources to a given management alternative.

ne multiresource concept is not new. Foresters ave been and are continuing to manage for mul- iple benefits. Today, however, more stringent onstraints are imposed on planning and management ue to changing law, special interests, and olicy. The forester must be able to provide a learer picture of expected outcomes from a anagement alternative prior to implementation.

brief overview of management direction reveals ne critical need for multiresource evaluation and rojection techniques, and for greater emphasis on nalysis and interpretation of multiresource data or deriving multiresource models and/or systems.

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per included in this proceedings by invitation.

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In 1960, the Multiple Use-Sustained Yield Act identified the multiple uses served by the National Forests (USDA 1978). However, the problem of determining procedures for allocating resources, such as timber and recreation, among competing interests was not resolved in the Act.

Succeeding acts made the responsibility more explicit: The Renewable Resources Planning Act (RPA) of 1974 assigned responsibility to the Chief of the Forest Service to periodically assess the supply and demand for forest and range resources (USDA 1976). In 1976, an amendment to the RPA, titled the National Forest Management Act (NFMA), outlined systematic methodology for planning the allocation, use, and future productivity of the National Forest System's multiple resources (USDA 1979). The amendment addresses the need to develop standards and methodologies for improving multiresource management planning and monitoring of the National Forest System.

Whereas Forests have traditionally been managed by a number of functional resource plans, the new process requires each Forest to prepare a single, integrated plan developed by an interdisciplinary team of forest specialists. The process is described as a nationally controlled and directed program which attempts to:

1. Determine for each Forest the operational and biological feasibility of achieving specified target output levels under given budgetary, operational, and production capacity constraints.

2. Determine production targets at Regional and Forest levels which minimize the total cost of production (economic, social, and environmental costs are considered) (Hartgraves 1981).

To accomplish this intense planning process requires data sets on all resources being managed at the forest level. Timber inventories are available and have proven useful in evaluating this resource in the planning process. However, there are no national continuous inventory methods applied for developing data bases on the many other resources currently managed.

Data bases developed by research in several areas of the United States could be used for developing prototype systems. Existing research data bases, used in concert with continuous forest inventory and other forest inventory data, do afford a starting point for development and testing of multiresource projection systems. Such systems will be plagued by data weaknesses. However,

they should be far superior to several methods presently available and in use.

ADAPTING MULTIRESOURCE MODELING TO FOREST PLANNING

The process of developing multiresource projection techniques is attainable, but at various levels of efficiency and effectiveness. As noted, many of the difficulties relate to data availability. Many National Forests have little multiresource data and must rely on estimates that cannot be supported by any level of statistical analysis. Other Forests with ongoing data inventory and/or cooperative research programs may have sufficient multiresource data to develop statistical models for several resources.

No Forest has sufficient single- or multiresource data from inventory to develop absolute values for population parameters. Yet, if scientifically valid procedures are applied to even partial data bases, more efficient and effective methods can be developed for understanding and projecting multiresource outputs.

Currently, we have only begun to investigate multiresource models for projecting resource outputs under differing management alternatives. Efforts by Boyce (1977) were successful in developing DYNAST-MB, a multiresource projection model for evaluating multiple benefits for eastern hardwood forests. This system is now being expanded for broader use in land management planning.

Research efforts in the Southwest have been effective in developing a prototype multiresource model for projecting multiresource outputs from ponderosa pine forests and the pinyon-juniper woodland type (Rogers and others 1981). The research program was designed to evaluate tradeoffs in multiresources that result from implementation of differing forest management alternatives. Research outputs have been expressed in management guidelines and analytical models.

Development of the prototype multiresource model was dependent upon a data base obtained from 20 years of research. The data were taken from over 40 research watersheds studied to determine impacts of management treatments on timber, range, wildlife, water, sediment, and scenic beauty.

Results of the long-term research effort in the Southwest revealed aspects of multiresource modeling that could be helpful to researchers undertaking similar efforts. These aspects involve defining appropriate analytic technique and model structure in model development, as well as defining appropriate procedures for model use after development.

Developing Multiresource Models

Efforts should begin with evaluations of existing data that can be utilized in such an effort. Where insufficient and/or unreliable data exist, assessments should be made of minimal cost approaches to structuring of data bases that could be effective in developing resource models or calibrating models transported from other areas. Even before data bases are in place, conceptual multiresource models can be structure to address specific problems. Many systems analysis and operation research techniques exist for development of models or systems. Linear programming, goal programming, integer programming, nonlinear programming, dynamic programming simulation, queuing theory, decision theory, and network theory can be used, depending upon the problem addressed and data available.

Simulation is used by modelers because they can accomplish many objectives without extensive dat bases. Bare (1971) gave several reasons for use of simulation. These include: (1) the technique is versatile, enabling it to be used for a variety of purposes; (2) models and systems can be constructed to tailor fit the situation; (3) models and systems can be built around an existi data base without requiring major data gathering efforts; (4) "quick and dirty" models can be developed with short lead times to provic timely information; and (5) "quick and dirty" solutions are often satisfactory when one understands that the actual implementation of th prescribed plan is likely to be modified somewh on the ground.

Any model developed for forest planning should respond to the manager's needs to meet the requirements of NFMA, or more generally impleme effective management practice. The following outline illustrates general areas of capability that are important in multiresource models developed for forest planning.

--A main program to control the simulation and call other components in proper sequence. It should provide capability for simulating severa management alternatives during a single program execution.

--An input and initialization component that reads user instructions and a description of th current forest stand. An interactive question-answer dialogue is most effective, and enables the user to select different tree species, choc among optional models for some species, and define variables that describe overstory, under story, forest floor, and environment.

--Resource projection components to simulate resource outputs on an annual time step. Simul tions should include:

1. forest growth and yields;
2. herbage yields and carrying capacity;
3. forest floor, snag, log, and debris accumulation and decomposition;
4. water yields;
5. soil loss; and
6. wildlife habitat.

--Activity simulators to provide the manager with methods of simulating the implementation of various forest prescriptions under differing management alternatives. Areas of simulation capability should include various methods of tree cutting, regeneration, salvage cutting, range improvement, prescribed burning, site preparation, and fuelwood removal.

--Output and summary component simulators to provide summaries of the effects of treatments on resources. Standard output should include information required in forest planning. Optional outputs could include detailed summaries of individual resource and activity impacts.

Implications to Management

The benefits that multiresource research and modeling can offer to forest management planning are many. Most important is the ability to evaluate complex tradeoffs that occur in a forest area when management actions are taken. Because discerning publics are scrutinizing all potential impacts of planned change, it is necessary to identify both the individual and the interactive impact of a management action.

With the important need and opportunity to improve our capability, are we gaining ground? And if not, why not, and what can be done?

Efforts are being made, and some are extensive. The Forest Service has adopted FORPLAN, a linear program resource allocation model, for use on all National Forests (Gilbert and others 1983). Using information from analysts or multiresource projection models, FORPLAN can provide the manager with guidelines as to the best management alternative to pursue.

Analytic capability is also being improved through application of new hardware systems. Compatible systems are currently being manufactured for assignment to each National Forest. In addition, Federal and university research is ongoing to improve knowledge of how individual resources react to various management actions.

Federal and university research is also developing new resource projection models for use in planning and management. As noted, extending these efforts to multiresource modeling is occurring, but at a slower pace. The availability of effective multiresource data impedes progress, but probably just as important are the actions of researchers and managers.

Researchers have too often taken the "ivory tower" approach to modeling. The results are usually not an appropriate solution to the manager's problem. Managers then become skeptical of the real contribution modeling can make to management science.

Grayson (1973, 1975) indicated that managers may be reluctant to support or use these types of efforts because: (1) analysts take excessive time to respond to managerial requests, (2) data needed for many models are inaccessible even after models have been constructed, (3) many managers are still uncomfortable and not familiar with systems and models and are resistant to use them, and (4) many analyst groups produce systems and models that barely resemble the real world.

Yet it is a foregone conclusion that managers must use analytical models and systems to keep pace and research must assist in their development. To do the job effectively requires a unique level of understanding and cooperation from each. It also requires that the mystique of computers and modeling be resolved and cast in the same light as calculators and arithmetic. They are simply another stage of development.

Managers and researchers alike must be aware of the difficulties associated with model development. Further, identified weaknesses and strengths must be the guidelines for their use. In this regard, both the researcher and manager have responsibility for their correct use.

DIFFICULTIES IN MODEL DEVELOPMENT

It must be understood by both the manager and the researcher that multiresource models are abstractions of the real biological world. Developing an analytical model to accurately describe one wildland process such as timber growth is difficult. The task is more complex when many resource models are linked, as in multiresource modeling.

When a model must be further constrained to conform to a manager's requirements of brevity and simplicity, difficulties increase. That is, the model must capture the real world in the smallest number of variables possible, and with a minimal amount of complexity in the variable interactions. Normally, biological processes are not simplistic, and actions to simplify or constrain the model often increase error.

The researcher is always limited by his available data in structuring a model that is biologically reasonable and also affords prediction efficiency. Most established guidelines constrain the number of variables contained in the model to a smaller subset, which will provide the predictive efficiency appropriate to its intended use. The inclusion of all variables known to affect the natural process is normally illogical due to restricted data availability, marginal increases in predictive efficiency, and increased cost with increased data requirements and model complexity.

Once the researcher has developed a model, two factors limit his ability to make the model useful to the manager:

1. The accuracy with which the developed model defines the biological processes being evaluated.

2. The accuracy with which data selected for model development represent the total variation in the environment under evaluation.

If the manager wishes to transport a model to an area different from where it was developed, the researcher is faced with additional problems. The model's usefulness then depends upon the extent to which parameters that accurately describe natural processes in the new area differ from areas where the model was developed. That is, are the same parameters appropriate and adequate? And would the relationships among model parameters and structure be the same in the new area? Usefulness also depends upon the extent to which data differ, both in diversity and variability.

USING MODELS CORRECTLY

Models, developed with acceptable procedures, are sometimes misused. Correct use is critical, and it relates not only to how and where the model is applied, but also to how the manager or analyst uses the outputs. Models can be expected to fail on some occasions due to oversimplification of assumptions and relationships, rarely encountered situations that have not or cannot be properly modeled, or extreme conditions that have not been considered. Modelers are obligated to specify these constraints, and users must understand their significance. If managers deliberately use models or systems in questionable applications or blindly use outputs that are questionable, the true utility of models has been destroyed.

There is clearly an obligation to the researcher to clarify the capabilities and limitations of his modeling efforts. It is his responsibility to determine the quality of his predictions and present any constraints on the models which are appropriate.

It is not the responsibility of science or scientists to define a model as good or bad. There is no absolute test as to the validity or accuracy of a model, but only subjective judgments based on the proposed use of the model, the acceptable level of errors, the availability of alternative models, and other user-related practical considerations.

Given the information on a model's capabilities and limitations, the manager must decide on its use. Once he has decided to use the system, he has a responsibility to use it within the limits of its design and evaluation.

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INVENTORY PARAMETERS FOR VOLUME

ESTIMATION AND PROJECTION

David R. Bower

ABSTRACT: Traditional forest inventory parameters are described in relation to volume or product estimation and in relation to growth projection. Parameters or attributes described include (1) stand table with impact on products and value, (2) level of stocking with impact on present and future volume, (3) spatial distribution of stocking with impact on volume, (4) dominant height with impact on present and future volume, (5) tree form with impact on volume, and (6) competing species with impact on volume growth.

INTRODUCTION

This paper describes traditional forest inventory parameters, or attributes, useful for volume estimation and projection and shows how omitting an attribute or inaccurate measurements impact volume estimates. Examples are taken from loblolly pine plantations.

STAND ATTRIBUTES

Rustagi (1979) distinguishes between primary stand attributes, collected at time of inventory, and secondary stand attributes, predicted or calculated from the primary attributes. Examples of primary attributes are stand age, dominant height, basal area, trees per unit area, average diameter, and crown ratio. Secondary stand attributes include site index (unless the height of dominants is measured at base age), relative density, and volume per acre.

MacLean (1979) describes the use of treatment opportunity stratifications, for example, stratifying clumps within the stand as candidates for precommercial thinning. Other treatment stratifications for a setting include brush control, fertilization, or commercial thinning.

Depta (1974) summarizes attributes which can be used to generate stand tables. His data inputs include basal area per acre, number of trees per acre, minimum d.b.h., quadratic mean d.b.h., maximum d.b.h., the associated height for each d.b.h., and stand form (even or uneven aged).

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The importance of stand table estimation will be discussed in a later section.

Several attributes in addition to diameter and height have been suggested for tree volume estimation. A taper system by Dell (1979) uses crown ratio for predicting product yield, whereas Matney and Sullivan (1979) report that form quotient is the most important variable for volume estimation after d.b.h. and height. Frazer (1979) discusses stratification by height, in addition to fitting of diameter and height, to improve tree taper estimation. Sprinz and others (1979) show that form class is relatively constant over a wide range of densities, but form class increases with age. The impact of change in tree form on volume estimation will be presented later.

Bower and Clason (1981) suggest the use of age in addition to tree diameter and height for estimating loblolly pine plantation component weights (stem wood, stem bark, branch wood, branch bark, and foliage). Relative tree component weights, of interest in defining hog fuel opportunities, are shown to vary by total age in loblolly pine plantations. For example, percent dry weight of stem wood ranged from 34 percent for 6-year-old trees to 77 percent for 30-year-old trees.

Key parameters for growth projection normally include age, stocking (trees per acre, basal area, or relative density [Reineke 1933]), competing species, and site quality.

Key variables in site quality estimation include site preparation treatments (cut with KG blade and pile, roll and chop, ripping, bedding, and others), soil series, topography, and climate. Several of these variables may be integrated through soil site equations to provide estimates of site index. A key to reliable dominant height projections is the development of representative site index curves through stem analysis and an objective procedure for site tree selection. Selection of a constant number of site trees per unit area, for different aged stands, appears to be more consistent for stem analysis-based site curves.

A final attribute for intensively managed plantations includes appropriate codes for genetic families. Growth projections can be modified for plantations based on gains exhibited from progeny tests.

Although these attributes can be included in a forest inventory, the choice depends on a forest manager's objectives and on incremental costs and values of obtaining the attributes. In the following section, I will discuss how some of these attributes affect volume or value estimation.

IMPACT OF STAND ATTRIBUTES ON VOLUME ESTIMATION

Errors or omissions in measuring an attribute affect estimation of (1) stand table, (2) stocking, (3) spatial distribution of stocking, (4) dominant height, (5) tree form, and (6) competing species.

Stand Table Estimation

Estimates of number of trees per acre by diameter classes provide information on product opportunities for thinnings or final harvest. Product opportunities include posts, poles, chip-n-saw logs, band saw logs, and plywood logs. In addition to these solid wood opportunities, additional products include fiber and hog fuel. Because product values rise with increasing tree size, higher stand values are calculated when a normal "bell-shaped" tree frequency distribution by d.b.h. classes is used than if all trees were assumed to be identical in size (equivalent to the average-sized tree). This is due to the linear relationship of value ($/cubic foot) with diameter and to the nonlinear relationship of tree volume with diameter. For data from two Louisiana loblolly pine plantation studies (aged 22 and 30 years) (Sprinz and others 1979), I estimated dollar value per acre to be 3 to 4 percent higher given the actual diameter frequency distribution, as compared to evaluating the "average-diameter tree," given the same volume per acre. Thus, stand average models could underestimate value by not taking into account the frequency distribution of diameters.

Stocking

A recent cruise of 24 young (6-year-old) loblolly plantations indicated a coefficient of variation (cv) (between 1/40th-acre plots) for stocking of 39 percent and for dominant height of 15 percent. Given a cv for stocking and an allowable error, sample size could be calculated. What value should be used for allowable error? Table 1 shows how errors in stocking determination at age 10 are expected to translate into errors in volume at age 10, 20, 30, and 40 years. According to yield tables by Hafley and others (1982), the impact of errors in stocking on volume estimates becomes less as the projection period increases. This is because low-density loblolly plantations eventually catch up in volume with high-density plantations. This relationship is also demonstrated by a long-term spacing study at Homer, LA (Sprinz and others 1979).

If allowable error is set at 20 percent for stocking at age 10, volume should be estimated at age 10 with slightly higher accuracy (table 1.), but projected volume to age 40 should be within ±2 percent. Projected average diameter varies somewhat more than volume, about ±5 percent.

Table 1.--Effects of sampling errors in stocking on estimated[1] volume yield by age, for site index 50, loblolly pine plantatio

Age	Error in estimated volume	
A. Underestimate stocking at age 10 by 122 trees/acre (455 vs 577), -21 percent		
	Ft³/acre	Percen
10	- 59	-15
20	-219	-13
30	-205	- 7
40	- 49	- 2
B. Overestimate stocking at age 10 by 176 trees/acre (753 vs 577), +30 percent		
10	+ 69	+18
20	+225	+13
30	+211	+ 8
40	+ 38	+ 1

[1]Volume predictions from Hafley and others (1982).

Spatial Distribution of Stocking

Variation in stocking (stems per acre) was determined from five young loblolly pine plantations in Arkansas. Plots were grouped into stocking classes to match the age 10 stocking classes provided in published yield tables (Haf and others 1982). Volume per acre was estimate at age 10 and at age 40 for each stocking class (table 2).

Table 2.--Estimated[1] volume at age 10 and at ag 40 by stocking levels at age 10-- loblolly pine plantation

Stocking age 10	Percent of plots	Volume Age 10	Age
Stems/acre	Percent	---Ft³/acre---	
255	34	369	3,
368	34	490	4,
575	26	668	4,
749	4	778	3,
1,013	2	889	3,
Estimated volume for average stocking:		528	4,
Estimated volume weighted by stocking:		515	3,
Percent difference:		2.5	

[1]Volume predictions from Hafley and others (19

A weighted average volume was obtained for all classes. Volumes were also estimated for "average" stocking and were only 2.5 percent higher than corresponding volumes weighted by stems per acre. The weighting procedure is more accurate, but differences are not large.

Dominant Height

The effects of relative errors in stocking on projected volume tend to diminish with time, as do effects of relative errors in dominant height. The magnitude of impact on volume, however, is greater for relative errors in dominant height (table 3). Even with long-term volume predictions (30 years), height errors continue to lead to substantial volume errors.

Table 3.--Effects of sampling errors in dominant height on estimated[1] volume yield by age, for 8- by 8-ft spacing, loblolly pine plantation

Age	Error in estimated volume	
	Ft³/acre	Percent
10	+284	+74
20	+860	+50
30	+980	+36
40	+899	+29

[1]Volume predictions from Hafley and others (1982).

Tree Form

Table 4 shows how form class, form factor, and the "b" coefficient of volume on D^2H equations tend to increase with age.

Table 4.--Summary of age, form class, form factor, and "b" coefficient of volume on D^2H model for several loblolly pine plantation data sources

Data source	Total age	Form[1] class	Form[2] factor	"b"[3] coeff.
Smalley & Bower (1968)	10-31		0.367	0.0020
Sprinz & others (1979)	22	70	.376	.0020
Sprinz & others (1979)	30	76	.378	.0021
Hope, AR (unpublished)	41	81	.416	.0023

[1]Form class = Diameter inside bark at 16 ft./diameter outside bark at 4.5 ft.
[2]Form factor = Volume tree/volume cylinder,with same d.b.h., total height.
[3]Model: Vol = b X d.b.h.² X Tot. Ht.

While this small sample confounds geography and age, other data sets support the trend of increasing form with increasing age. The volume estimation system should be sensitive to changes in tree form with age.

Competing Species

Clason (1978) showed that removal of hardwoods from a 7-year-old loblolly pine plantation led to a 45 percent volume growth increase by age 12. Bower and Ferguson (1968) showed that increased shortleaf pine basal-area growth rates (+31 percent) also occurred from understory hardwood removal and that when only part of the understory was removed, starting with the larger hardwood stems, the overstory's growth response was proportionately less. These results indicate that inventory data for competing species may substantially improve growth forecasts for the primary species.

CONCLUSIONS

Among various inventory attributes for volume projection, dominant height is probably the most important. For loblolly pine plantations, the number of trees per unit area has a large impact on volume at time of assessment but has much less impact on long-term volume projections. An associated error occurs when trees per unit area are estimated on average d.b.h., which will influence value estimation. Competing species may have substantial impact on short-term volume projections. Stocking variability within plantations appears to have small impact in volume assessment. Variation in diameter, as expressed by the estimated stand table, can have important effects on tree value and on product opportunities. Finally, improvements in tree form with age should be quantified with the volume or taper system used, or else additional measurements should be taken to quantify form changes. These results are based on a sample of loblolly pine plantations and may differ somewhat with geographic variation in loblolly pine and with other species.

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STEM ANALYSIS: A CONVENTIONAL APPROACH TO VOLUME DETERMINATION

J. E. Brickell

3STRACT: This paper discusses the bias in alculated volumes of felled and dissected trees nich is due to the customary assumption of araboloid tree bole shape. It examines the elationship of bias magnitude to measurement nterval and presents guidelines for meeting ccuracy requirements. A study of volume deter-ination methods reveals that although several ensuration techniques are effective, if stem easurements are closely enough spaced, Smalian's ormula is most often used because it uses the imple geometric solid that most closely repre-ents most of the tree and is easy to use.

ITRODUCTION

though the title of this paper is "Stem Analy-s: A Conventional Approach to Volume Determina-on," stem analysis involves a lot more than olume measurement. It includes measurement of a ee's diameter and height growth at various ints in time; however, this paper concerns ly volume determination from measurements on lled trees. Measurements can be taken on anding trees, if one wants to climb or use a ndrometer. Felled trees are easier to measure, wever, because one then can use a diameter tape calipers, or buck the tree into stem segments d measure cross-sectional dimensions with a ler or tape. Bark thickness and any desired owth information can be taken, and internal fect can be measured. Precision of measurement greater on felled trees, and mistakes are less kely.

CKGROUND

tree stem is a complex geometric solid--so mplex that to describe it perfectly with a thematical expression is impossible. Even if were possible, each tree would require a fferent expression. Fortunately, we don't have describe a tree or log perfectly--close is od enough. We can get close enough by adopting simple geometric model to represent the tree em or segments of the stem and estimating model rameters from measurements taken on the tree. curacy in determining stem volume of a felled ee depends upon two things:

1. The nature of the mathematical model used to represent the stem or stem segments.
2. The kind and number of measurements taken on the tree.

A good model requires fewer measurements to attain a given level of accuracy than does a poor model. On the other hand, if the right kind of measurements are taken, spaced closely enough on the tree, almost any model will give adequate results providing it exhibits a circular or elliptical cross-section. Such models would include the cylinder, paraboloid, cone, and neiloid. Since I'm slinging these terms around it might be a good idea to describe them.

Cone: Everyone knows what a cone is. It's a geometric solid in which diameter decreases at a constant rate relative to length as length is increased toward the apex.

Paraboloid: A geometric solid in which diameter decreases at an increasing rate relative to length as length is increased toward the apex. The square of diameter decreases at a constant rate.

Neiloid: A geometric solid in which diameter decreases at a decreasing rate relative to length as length is increased toward the apex.

Frustrum is just a Latin word meaning "piece cut off" which has been adapted in mathematics to describe a segment taken from a geometric solid.

According to Fernow (1907), a German forester named Oettelt first used a mathematical model for a tree stem in 1765. He used a conic model. After looking at *Pinus ponderosa* var. *scopulorum* in extreme eastern Montana, I can see how his model could have been accurate. For most trees, though, modeling the tree stem as a series of paraboloid frustra seems more accurate, and this approach generally has been accepted as standard since about 1820. It has been long recognized, though, that the top portion of the bole more closely resembles a cone than a paraboloid, so the usual practice has been to model the top portion of the stem as a cone and the rest as a series of paraboloid frustra. Some people have recognized that the butt portion of the tree more closely resembles a neiloid than a paraboloid; however, Bruce (1970) used a solid model composed of a quasiconic frustrum surmounted by a cylinder to approximate the shape of Douglas-fir (*Pseudotsuga menziesii*) butt logs.

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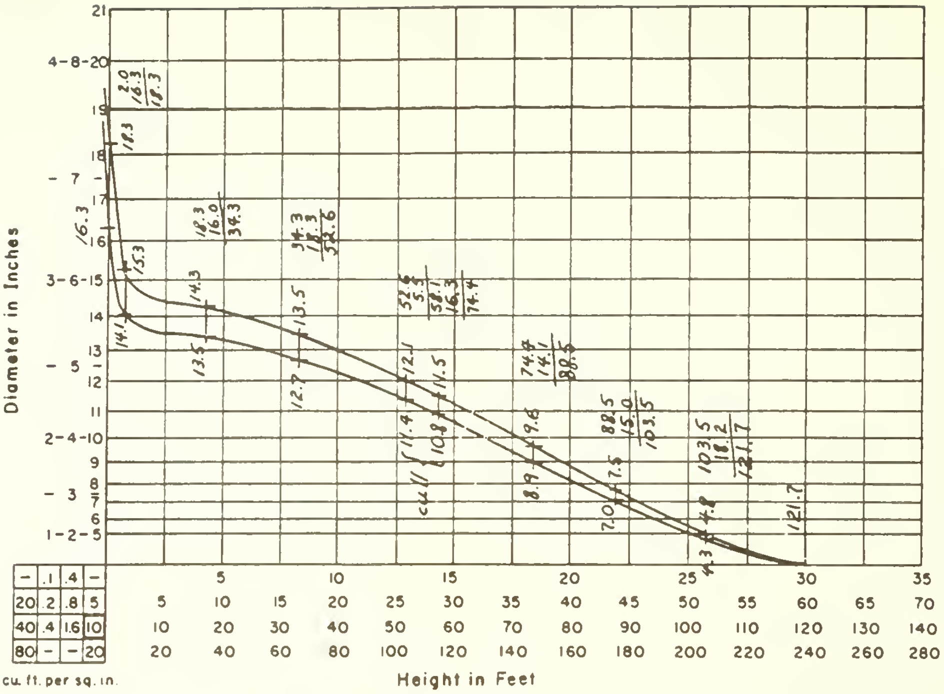

Figure 1.--A plotted tree system profile on USFS form 558a.

Reineke (1926) devised an approach to volume determination which was ingenious in its simplicity and involved no explicit assumption at all about stem form models. He used a piece of graph paper called form 558a on which the vertical axis was scaled in terms of squared diameter. The horizontal axis was tree length. One had only to plot his stem measurements on form 558a, sketch in a curve to connect them, and measure the area under the curve with a planimeter. A simple multiplication could then convert graph area to tree volume. An example of a plotted stem profile is shown in figure 1.

With this approach, the only assumption relevant to a geometric model resulted from the way in which the taper curve was sketched. For example, most people think that tree diameters get smaller toward the tip. If a measurement seemed to suggest the contrary, the sketcher might ignore it and make his curve taper toward the tip anyway.

Since Reineke's time a number of people have chosen not to sketch the taper curve by hand but to fit a mathematical function to the measurements. Cubic volume of the tree bole between any two points is obtained by integrating the taper function between those points. This amounts to just evaluating a function if the taper curve is integrable in closed form. Fitting a taper curve requires some assumptions as to proper curve shape, but they need not be as restrictive as the adoption of a specific geometric solid for a model. Use of taper curves requires more statistical skill than is possessed by most foresters, and until computers were available in the early 1960's, the burden of calculation made fitting taper curves impractical.

Despite the superior accuracy of taper curves, properly used, for volume determination, many people still use the paraboloid frustrum model for most of the tree stem. They use Smalian's formula, and the paraboloid shape is implicit in that formula. Many people know that Huber's formula also assumes a paraboloid shape and that it is superior in use to Smalian's. Why, then, is it not more commonly used? Because it requires a diameter measurement at the center of the stem segment, and, if measurements are not taken at just the right intervals, it is impossible to position them at the center of a stem segment without leaving some of the tree bole unaccounted for. This is illustrated in figure 2. So Smalian's formula it is, for better or worse. The trouble is that because of the paraboloid shape assumption, Smalian's formula tends to overestimate volume. How much this positive bias amounts to depends upon actual shape of the tree bole and the frequency with which measurements are taken.

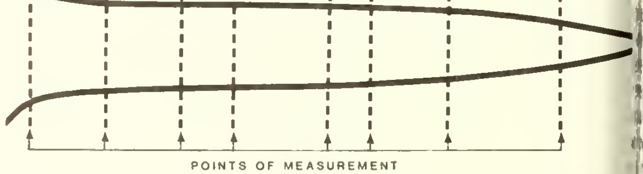

Figure 2.--A situation where Huber's formula can't be used.

Table 1.--Total cubic-foot volume differences: four formulas[1] compared with Newton's formula; differences expressed as a percentage of volume computed by Newton's formula (Dilworth 1961)

Log group	Formula: Huber's	Smalian's	Rapraeger's	Sorenson's
	STUDY I (DOUGLAS-FIR)			
Butt	-4.9	+ 9.9	- 0.1	- 4.5
Intermediate	-0.8	- 1.6	- 6.2	-10.6
Top	+0.6	- 1.4	-16.3	-22.1
Weighted average	-2.9	+ 5.8	- 4.7	-13.8
	STUDY II (WESTERN HEMLOCK)			
Butt	-5.6	+11.2	+ 0.5	- 2.7
Intermediate	+0.5	- 1.0	+ 0.3	- 3.7
Top	-2.1	+ 4.4	-23.0	-28.6
Weighted average	-2.2	+ 4.4	- 1.4	- 5.2

[1]Huber's formula: $V = \frac{\pi}{4 \cdot 144} D_m^2 L$

Smalian's formula: $V = \frac{\pi}{4 \cdot 144} \frac{(D_\ell^2 + D_s^2)}{2} L$

Rapraeger's formula: $V = \frac{\pi}{4 \cdot 144} (D_s + \frac{L}{16})^2 L$

Sorenson's formula: $V = \frac{\pi}{4 \cdot 144} (D_s + \frac{L}{20})^2 L$

Newton's formula: $V = \frac{\pi}{4 \cdot 144} \frac{(D_\ell^2 + 4D_m^2 + D_s^2)}{6} L$

where

D_s = diameter at the small end of the stem section

D_ℓ = diameter at the large end of the stem section

D_m = diameter at the middle of the stem section

L = section length

V = cubic volume

alian's formula gives reasonably accurate sults for segments in the middle portion of the le but usually grossly overestimates volume in e butt portion. Dilworth (1961) showed the gnitude of errors that can be expected from ber's, Smalian's, Rapraeger's, and Sorenson's rmulas. His information is summarized in table 1.

rnes (1945) reported that Smalian's formula erestimated cubic volume in butt logs of stern hemlock by 10.8 percent. Most forest nsuration texts recognize that a truncated raboloid is not a satisfactory model for the ver portion of a tree stem, and usually suggest neiloid. Bruce (1970), however, has shown that neiloid is also inadequate. He had good sults with an equation that corresponds to a nposite solid comprised of a cylinder with the diameter of the small end and a concave solid of revolution resembling a truncated conoid.

Spaeth and others (1952) indicated that overestimates from Smalian's formula may not always be confined to the butt section of trees. In their experiment, Smalian's formula gave volume estimates for fenceposts 7-ft long that averaged 6 percent larger than volumes measured by displacement of water in a tank.

Grosenbaugh (1966) emphasized that trees are not simple geometric solids; therefore, some error must be expected from formulas based on simple models. He suggested that such error can be kept within acceptable limits by keeping measurement intervals on the stem short enough so that diameter at the small end of a stem section is more than 0.8 the diameter at the large end.

Table 2.--A comparison of tree volumes computed by Smalian's formula with volumes measured by water displacement (Young and others 1967)

Species	Computed volume as a fraction of water displacement volume		Ratio
	8-ft sections	16-ft sections	
Spruce	0.997	1.035	1.038
Fir	1.032	1.096	1.061
Hemlock	1.035	1.102	1.065
White pine	1.003	1.042	1.039
Cedar	1.072	1.234	1.151

Young (1967) and Young and others (1967) reported results of an experiment in which volumes of felled trees were calculated with Smalian's formula using stem measurements spaced 8 and 16 ft apart. Volumes regarded as correct were measured by immersing tree pieces in a tank and measuring the amount of water displaced. Table 2 summarizes their results. Spacing measurements 16 ft apart led to volume measurements that ranged from 3.8 to 15 percent greater than those obtained by a measurement spacing of 8 ft.

Integrating a taper curve really assumes a cylindrical stem segment shape, yet if the taper curve is accurate, that procedure will yield the best estimate of tree volume short of water displacement. The reason is that the stem segments assumed in the integration process are of infinitesimal length.

Clearly, a number of different formulas will work if stem measurements are closely enough spaced. Smalian's is most often used because it combines the paraboloid--the simple geometric solid that most closely represents most of the tree--with simplicity and ease of use.

So how closely should measurements be spaced to achieve any given level of accuracy if we are to use Smalian's formula? Is there any general rule that can be followed?

A QUICK AND DIRTY INVESTIGATION

To investigate this question I conducted an experiment in stem measurement by computer simulation. I selected the most accurate taper curve that I could find in the literature, which was the Max-Burkhart splined polynomial fitted to yellow poplar (Liriodendron tulipifera L.) (Martin 1981). This equation was most accurate both in precision of fit and in its inherent flexibility to fit different portions of a tree. Also, of the several hardwood species to which the equation was fitted, yellow poplar is most like a conifer in form.

Over a diameter breast height (d.b.h.) range of from 4 to 20 inches and a height range of from 20 to 130 ft (depending upon d.b.h.), I calculated tree volumes in two ways:

1. By dividing the tree into segments, calculating diameter outside bark at each end with the taper curve, and applying Smalian's formula.

2. By evaluating the integral of the taper curve between the lower and upper ends of the stem segments.

Segment volumes calculated by each method were accumulated to obtain two different total tree volumes. Stump volume was calculated in the sam[e] way by both methods, namely, as the volume of a cylinder 1-ft tall having the diameter predicted for the tree at 1 ft in height by the taper equation. This procedure is often followed when calculating felled tree volume. The integral of the taper curve between ground level and 1 ft may have given a rather larger volume, which whe[n] added into the tree's total volume would have tended to obscure the expected overestimate to b[e] obtained with Smalian's formula. Volume below stump height is often not as important as that above the stump anyway. Also, under method 1 (Smalian's formula), the topmost segment of the stem was treated as a cone, following the procedure usually employed in determining volume of felled trees. Both segment volume and total tre[e] volume were printed as well as stored in a computer system file for futher processing. Initially the comparison was made for segments [of] fixed length. Lengths were 1, 2, 4, 8, 12, and 16 ft. Then the comparison was made using segment lengths which were fixed proportions of total tree height. Proportions were 0.05, 0.10[,] 0.15, and 0.20.

RESULTS

The bias in total tree volumes calculated with Smalian's formula was positive in all cases. T[he] magnitude of the bias was clearly related to tr[ee] length and stem segment length. The volume bia[s] observations obtained in this way do not compri[se] a statistical sample; however, that did not sto[p] me from fitting a regression equation to the da[ta]

in order to characterize and quantify the relationship. The equation is:

$$B = b_0 + b_1H + b_2L + b_3F + b_4F^2 + b_5H^2$$

$$+ b_6H^{-\frac{1}{2}} + b_7L/H^2 + b_8L^2/H^3 + b_9L^{b_{10}}\ H^{b_{11}}$$

where

b_0	= -0.0419630	H	= tree height in feet
b_1	= 0.192412 x 10^{-3}	L	= stem segment length in feet
b_2	= -0.482282 x 10^{-2}	F	= L/H, segment length as a fraction of tree height
b_3	= 0.523567		
b_4	= -3.90049		
b_5	= 0.689265 x 10^{-6}	R^2	= 0.97507
b_6	= 0.151162	S_{yx}	= 0.002803
b_7	= -6.43048		
b_8	= 26.8953		
b_9	= 0.845992		
b_{10}	= 1.97294		
b_{11}	= -1.60748		

The coefficient of multiple determination and standard error of residuals cannot be interpreted as they could if the data were observations on actual felled trees, but they do indicate goodness of fit. Notice that in this equation F = L/H, so that either F or L will determine the other for any particular tree height. Figure 3 shows bias associated with Smalian's formula plotted over tree height for several different spacings of measurement. Measurements spaced 1 or 2 ft apart yield little bias regardless of tree height. A measurement spacing of 4 ft gives a bias of 2 percent or less for all tree heights. Measurements spaced farther apart than 4 ft may result in an unacceptable overestimate, depending upon height of the tree and what the user considers to be acceptable. It is noticeable that the rate of slope change (second derivative of bias with respect to height) changes sign for the 4-, 8-, and 12-ft curves, as it does for the other curves in the region of height not on the graph. This can be attributed to two artifacts of the way in which volume calculations were carried out:

1. Stump volume was calculated in the same way under both Smalian's formula and taper curve methods. In shorter trees, stump volume is a greater proportion of total volume than in taller trees. A greater portion of the tree's volume being calculated identically by both methods tends to reduce the apparent bias of Smalian's formula for total tree volume in shorter trees.

2. With Smalian's formula method, volume of the stem's top segment is calculated with a conic model. This is much closer to the true shape, and the shape given by the taper curve, than is the paraboloid. In shorter trees the top segment contains a greater proportion of total volume than in taller trees. A greater portion of the tree's volume being computed with less bias tends to reduce the apparent bias of Smalian's formula for total tree volume in shorter trees. A longer interval between measurements accentuates this influence.

For the reasons given above, the central portion of the tree stem--the portion treated as a paraboloid--contains a smaller proportion of total volume in short trees.

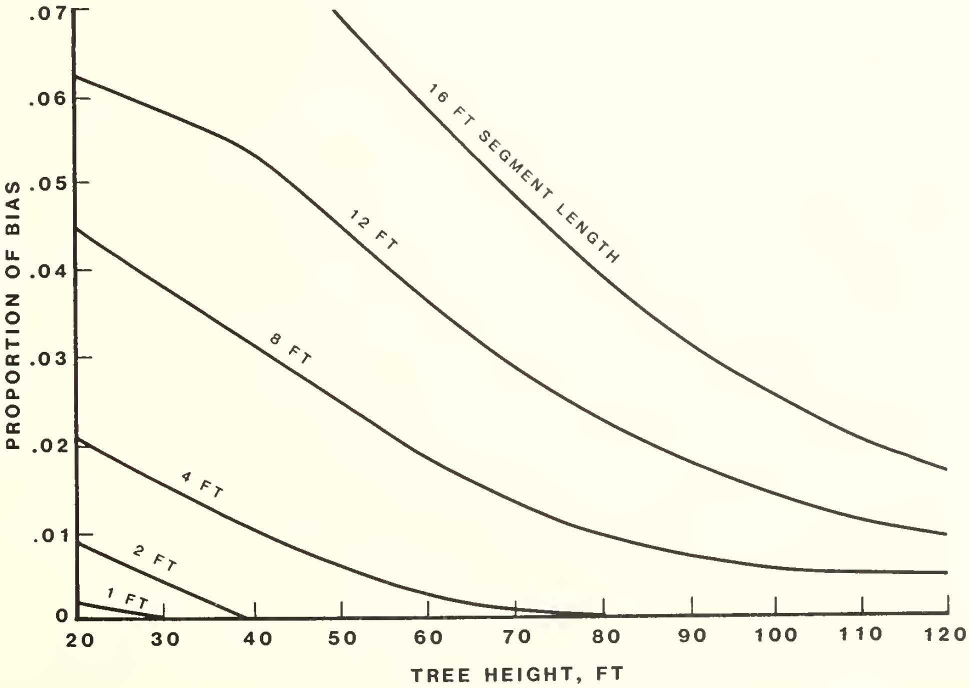

Figure 3.--The relationship between tree height, spacing between measurements, and bias of Smalian's formula.

Another feature of this chart can be noted: 4-ft measurement intervals for 40-ft trees, 8-ft intervals for 80-ft trees, and 12-ft intervals for 120-ft trees all give about the same amount of volume measurement bias. Evidently, for any given level of acceptable bias when using Smalian's formula, the appropriate spacing of measurements will depend upon height of the tree being measured. Recall the definitions of F and L in the bias regression equation. Figure 3 was created by evaluating the equation for fixed intervals of L and letting F be determined by L and H. (If the equation is evaluated for fixed intervals of F, figure 4 can be plotted.) Here again, for any particular segment proportion, shorter trees exhibit less bias than do taller trees, and this tendency is more marked for longer measurement intervals. The reasons are the same as for the reversal in sign of the rate of slope change in figure 3. An envelope curve is defined mathematically as a curve which is tangent to each of a family of curves. For this family of curves one can envision an envelope curve which is concave upward. The envelope curve defines, for each segment length proportion, a level of bias that will probably not be exceeded by using Smalian's formula regardless of tree height. For example, an interval between measurements which is 10 percent of the tree's height can be expected to give a 1 percent bias, or less. An interval of 15 percent will probably not give more than a 2.25 percent bias; a 20 percent interval, 4 percent or less, and so on. Apparently, if one wants the average bias of felled tree volume calculated with Smalian's formula to remain within some specified upper bound, this can be done at least cost by prescribing the interval between measurements on the stem as a certain proportion of stem length. With a little effort the regression equation could be solved for stem segment fraction given bias and height. The statistical problems involved in doing so wouldn't be a practical objection, but it seems just as easy to use a chart-like figure such as figure 4.

Specific numerical values given in this paper apply to yellow poplar in the Appalachians, for which the taper curve was fitted. The nature of the findings reported here will apply to all species with an excurrent bole. I could probably pass this off as an original piece of work--but I won't. Sixty years ago a German forester named Hohenadl reported the same results from an investigation on European tree species. He showed further that if one seeks a single key diameter to characterize a tree, then that diameter is more useful if it is measured at one-tenth the total tree height than if measured at breast height. Obviously, there are impracticalities in taking such a diameter, so we continue to use d.b.h.

Likewise, though the entire tree is accessible when it is felled, there may be impracticalities associated with using a fixed proportion of length as the measurement interval. For example, if we are stuck with board foot scaling diameters of 16-ft logs on felled trees, then the measurement interval will have to be 16-ft plus the trim

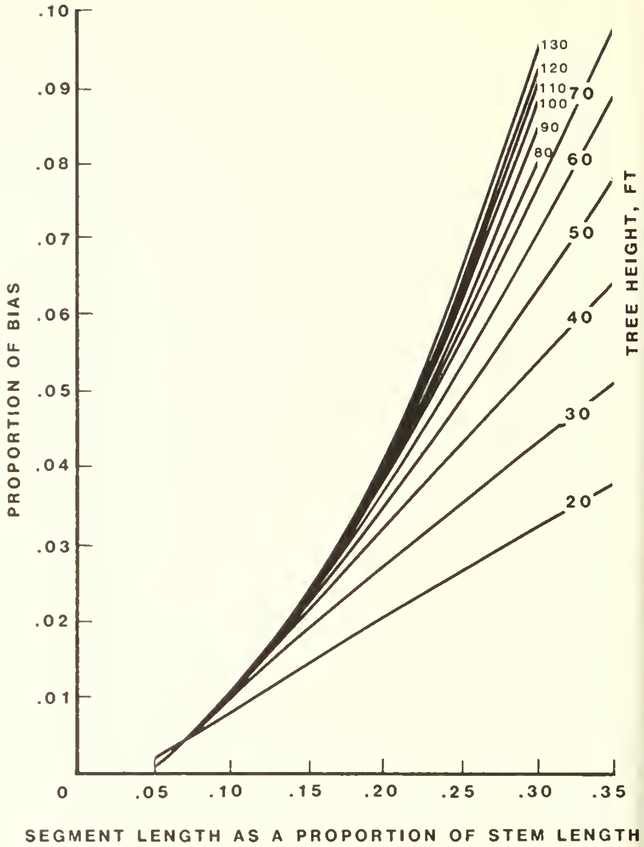

Figure 4.--The relationship between tree height, fraction of stem between measurements, and bias of Smalian's formula.

allowance or some fraction thereof. Sixteen and a half feet might keep cubic volume bias within acceptable bounds for the largest trees, but for shorter trees 8.25-ft might have to be used. If the tree is quite short, an interval of 4.12-ft might even be advisable. Such a set of measurements might provide for reasonably accurate cubic volume calculation and still ensure the measurement of scaling diameters.

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VISUAL SEGMENTATION FOR WOODLAND TREE VOLUME MODELS IN THE ROCKY MOUNTAIN STATES

J. David Born

ABSTRACT: Tree volume models used to generate volume tables are generally not available for woodland species such as pinyon, juniper, and oak. The variable form of these species presents problems for conventional volume model development procedures. A visual segmentation procedure using data estimated ocularly from standing trees can be substituted for destructive sampling. In a test, data from the visual method compared favorably to felled tree data in constructing volume models. Procedures are described to collect data and include the data collection with forest inventory operations.

INTRODUCTION

In recent years the demand for fuelwood and other local products from pinyon (Pinus), juniper (Juniperus), oak (Quercus), mesquite (Prosopis), and other species characterizing woodlands in the Rocky Mountain States has increased dramatically. During the 19th century these species were heavily utilized for fuel and to support mining activities; however, as fossil fuels became more available and mining activity decreased after the turn of the century, vast areas were left to reforest. Increased grazing and control of wildfires undoubtedly helped sustain and increase the acreage of land supporting woodlands. Although during this century woodland species have been considered a deterrent to forage production for livestock and game, attempts to eradicate the trees have been costly and largely unsuccessful on a long-term basis.

Since 1928, when the McSweeney-McNary Act directed the U.S. Department of Agriculture to keep a current inventory of the Nation's forest resources, Forest Survey has made periodic assessments of forest resources. Only recently, however, has Forest Survey reported more than general area statistics for woodlands.

Previously, the focus was on information about timberland, that is, land growing species used for industrial wood products. With the passage of the Resources Planning Act of 1974 and the almost concurrent increase in demand for wood as an energy source, Forest Survey jumped into the woodland inventory business in the Rocky Mountain States.

Since 1974, when we tested our first woodland inventory procedure on the Carson National Forest in New Mexico (Born and Clendenen 1975), we have conducted extensive inventories in all of the Rocky Mountain States. Since the beginning that procedure has included subsampling for data needed to construct volume tables. We call the procedure visual segmentation. The volume equations and tables for the Carson inventory have been published (Clendenen 1979).

Tree volume models, or volume tables, have generally not been available for most woodland species. The extremely variable form caused by species differences and treatment history precludes the use of general models over large areas. Of course, the high cost of destructive sampling alone is motivation for a search for alternative techniques.

SUBSAMPLING

We use fixed-area circular plots which are usually spaced on a sampling grid to sample woodlands. Plot sizes range from 1/20 acre to 1/5 acre, but 1/10-acre plots are the most common. A tree is measured for volume if the diameter near the base exceeds 3.0 inches.

The first tree tallied under 10 inches in diameter is selected for visual segmentation, as is the first tree over 10 inches. The next tree tallied over 18 inches is also selected, regardless of the size of the other two trees. This i[s] done to strengthen the volume models for larger trees, which are not common on the plots. The usual measurements are made on the trees selecte[d] for visual segmentation. These measurements are those common to most surveys with two exceptions

1. DRC. The tree diameter is measured at the base or ground line, with some exceptions (fig. 1). DRC means diameter at root collar an[d] although sometimes a misnomer, it is used as an acronym for a basal diameter measurement.

When a tree is multistemmed at or near the base an EDRC or "equivalent" DRC is recorded. The diameters for the stems are each squared and

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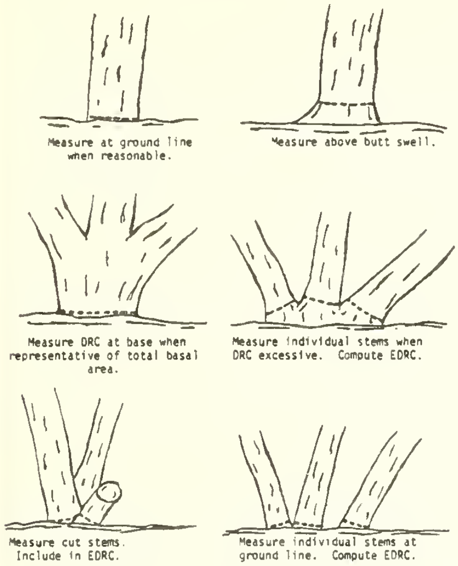
ummed, and the square root of the sum is the iameter of a tree of "equivalent" basal area--a imple procedure with a pocket calculator. Trees equiring an EDRC measurement are common.



igure 1.--Examples of DRC and EDRC measurements.

Trees with 3.0 inches or larger DRC or EDRC are measured for volume. A multistemmed tree needs only one stem this large, and any stem having a qualifying segment, regardless of diameter, is included in the EDRC. A qualifying segment must be at least 1 foot long and be at least 1.5 inches in diameter at the small end.

2. Number of stems. The number of stems measured for DRC or EDRC is recorded. This variable is used in our volume models.

If you are interested in our inventory procedures, please refer to one of our recent field manuals (U.S. Department of Agriculture 1982).

VISUAL SEGMENTATION

Trees are visually segmented in a manner similar to measuring felled trees for volume. Lengths and diameters are recorded for segments in each stem and branch in the tree. Remember, we measure any part of the tree that has qualifying segments, so both branches and stems are included to a 1.5-inch minimum diameter (outside bark). Figure 2 shows a tally form with two example

WOODLAND TREE SEGMENTATION RECORD

ate/County 0 8 1 0 3 7 — NFS Region/ BIA Area/ BLM Resource Area 0 — Forest/ Agency/ District 9 9 — Subunit/ Reservation/ Planning Unit 0 5

cation No. 0 1 2 3 — Owner 7 0 — Sample Area 0 3 — Date 6-25-85 — Crew D. Recorder, C. Cruiser

Pt. No. 03 Tree No. 01 Species 133 DRC 125 No. Stems 01
Total Ht. 16 No. Segments 014 Radial Growth 06 Estimator 01

Record Multiple Stems DRC Below

	1 - Foot Length Class	2	4	6	8	10	12	14	16					T
SUMMARY	1													
	2	3		1	1									5
	3			1										1
	4	2	5			1								8
	5													
	6													
TOTAL		5	5	2	1	1								14
DOT COUNT	1													
	2													5
	3													1
	4													8
	5													
	6													

Pt. No. 04 Tree No. 07 Species 065 DRC 344 No. Stems 04
Total Ht 32 No. Segments 109 Radial Growth 04 Estimator 01

Record Multiple Stems DRC Below

13.6	14.7	16.5	22.6		

	1 - Foot Length Class	2	4	6	8	10	12	14	16	20				T
SUMMARY	1	12	2											14
	2	16	12	14	1		1		1					45
	3	3	12	1	6									22
	4	2	4	3	3	2	2							16
	5			3		4	2	1						10
	6				1					1				2
TOTAL		33	30	21	11	6	5	1	1	1				109
DOT COUNT	1													14
	2													45
	3													22
	4													16
	5													10
	6													2

igure 2.--An example of segmentation recording form.

trees recorded. The first heading includes information about the plot, and the heading inside the box describes the tree. Multiple-stem DRC's are individually recorded in the boxes shown.

Segments are tallied by 2-inch diameter classes and 1-foot length classes using a dot tally. Figure 3 shows the preferred sequence for tallying segments in a tree to avoid missing branches and stems or even double tallying a portion of the tree. We have found that methodical application of the procedure is very important in assuring quality data.

Figure 3.--The order of segment tallies.

Most woodland trees are not very tall, but it is still difficult to estimate diameters and lengths in the upper part of a tree. To assist with this task we have adapted measurement poles developed at the Southeastern Forest Experiment Station (McClure 1968) to our needs. These 5-foot segment poles have both diameter and length reference markings, and they can be connected together as needed to reach the upper part of the tree.

Segment diameters near the base of a tree should be measured, especially if the stems are large. One cooperator asked his crews to climb the trees and make the measurements--quality data for sure!

DATA ANALYSIS

Procedure Verification

When most of the measurements used to compute tree volumes are visual estimates, one might reasonably question the reliability of the results. To determine reliability we conducted a study in Nevada to test the visual procedure against felled tree data. The results of this study are reported in Born and Chojnacky (1985). This publication also documents the current visual segmentation field procedure and contains complete field instructions and a tally form.

Figures 4 and 5 briefly indicate the results of the verification study. The regression lines developed from visual data tend to follow the felled tree data line closely except for larger trees. Here, for juniper, the direction of the difference depended upon the estimator. For pinyon all of the estimators underestimated the actual tree volumes for larger trees.

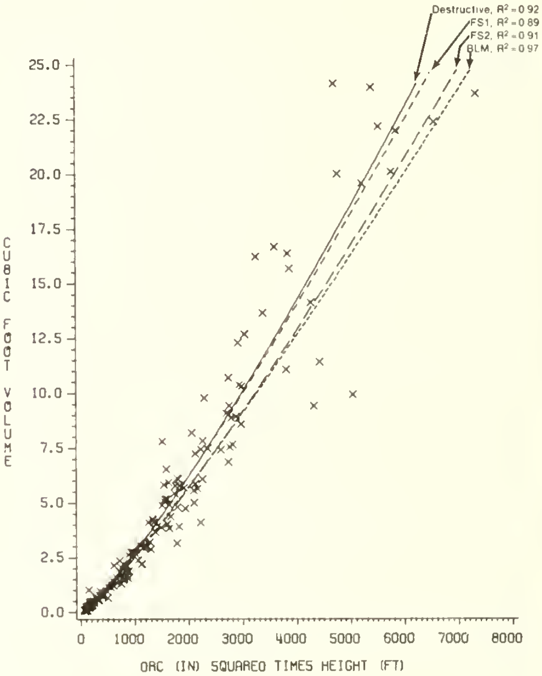


Figure 4.--Pinyon destructive segmentation data in cubic feet with a regression curve (solid line) and three curves for visual estimates overlaid.

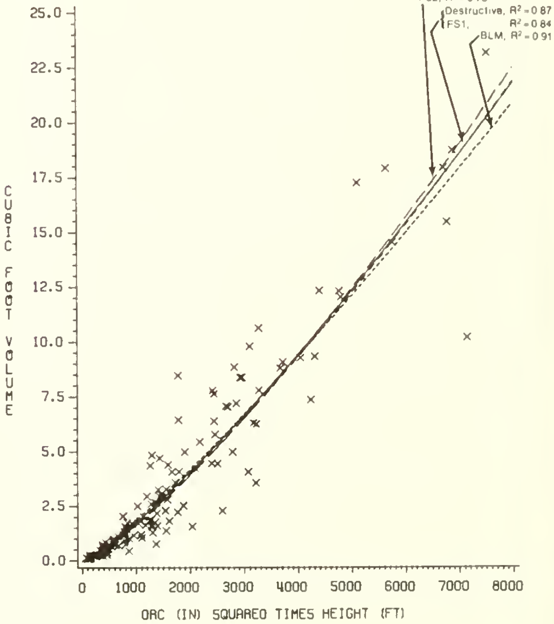


Figure 5.--Juniper destructive segmentation data in cubic feet with a regression curve (solid line) and three curves for visual estimates overlaid.

We believe that the underestimates for larger trees can be remedied by improved training and diligent use of the segment poles. Coincidentally, the three estimator groups ranked proportionate to their training and experience.

As expected, the visual method results in more variability in the data; however, this does not present any problems for the regression modeling if the procedure is carefully applied to avoid bias. More recent data we have collected tend to support these conclusions.

Volume Models

The segment volumes are computed by class and summed to obtain the total tree volume. Each segment is assumed to be a paraboloid frustum, and Huber's formula (Husch and others 1982) is used to compute the volume. This formula uses only the length and midpoint diameter.

The volumes are gross volume and include dead material that is usable for fuelwood. When volume has been cut from sample trees, we reconstruct the missing material or take the next appropriate tally tree, so that our volume models express total gross volume.

The tree volumes are used to develop a regression model using DRC, total height, and number of stems as predictor variables. Other variables are available, such as crown size and volume, but they add little that accounts for model variation. We have almost standardized our woodland tree volume models using the following form:

$$V = [a + b(DRSQH)^{1/3} + c \cdot STEM]^3$$

where: V = gross tree volume

DRSQH = DRC (inches) squared times height (ft)

STEM = 1 for single stem tree, 2 for multiple stem tree

The volume equation coefficients for woodland species in five States are included in Chojnacky (1985).

These equations were not intended for use in determining the volume of individual trees, so they should be used with caution. We believe the equations can be used effectively for inventories and cruises in the areas in which they were developed.

The volumes computed from the equations include all stem and branch volume to a 1.5-inch minimum diameter. We consider this minimum diameter to represent maximum practical utilization for fuelwood; however, I am sure that all of you have seen fuelwood cutting areas where the average minimum diameter was larger than this.

We have developed adjustment factors to apply to our equations to reduce the volumes for minimum diameters up to 6 inches (Chojnacky in preparation). The factors are simply ratios to multiply by the total tree volumes from the equations to obtain the utilizable volume at the new standard.

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BRIEF HISTORY AND DISCUSSION OF

BIOMASS ESTIMATION FOR TIMBER TREE SPECIES

Eugene M. Carpenter

ABSTRACT: This paper gives an overview of the history, modeling techniques, availability, and application of equations and methods to estimate timber tree biomass in the United States.

INTRODUCTION

The purpose of this paper is to introduce biomass estimation to field foresters and others not familiar with these estimation techniques, to show sources of biomass information, and to briefly discuss biomass modeling methods and their application.

HISTORY OF BIOMASS ESTIMATION

A French forester, J. Pardé, published a review article in Forest Products Abstracts in August 1980 entitled "Forest Biomass." He outlined the development of studies on the biomass of trees and forest stands throughout the world and contended that, although forestry schools have existed for 150 years, only recently have researchers addressed the question of woody biomass. Between 1950 and 1979 many works on mensuration and production appeared. But up to 1974 most dealt only with the volume of forest trees. Interest in the weight of trees stemmed from the conjunction of three factors:

1. Weight scaling, especially by fiber-oriented industry, which began in the early 1960's but which was limited to the merchantable bole component.

2. Scientific "fundamentalists'" concern for documenting the biologic productivity of forest ecosystems, which also increased markedly in the 1960's.

3. The 1973 oil crisis and the attention focused on the utilization of wood as a renewable natural resource for both energy and chemicals.

The latter two especially could be analyzed most readily in terms of the dry weight of plant material.

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To these factors we might add:

4. The development of whole-tree chippers and the need to determine whole-tree weight to convert inventory and harvest to a tons-per-acr basis.

5. New product development capable of usi a greater portion of a tree.

6. The concurrent interest in nutrient capital cycling to determine what is removed wh whole trees are harvested from the site.

It is not surprising that foresters were interested only in the volume of wood in boles and, at best, large branches. This interest wa totally driven by the raw materials wanted for industrial processes and the economics of harvesting. Merchantable volume to a limited t diameter, such as 9 inches or 4 inches, could b calculated by accepted standard formulas, such Huber's, Newton's or Smalian's, by stem analysi taper functions, or a variety of log rules, suc as International, Doyle, Decimal C, and the lik Bole volume was satisfactorily expressed in boa feet, cords, or cubic feet.

The first idea for estimating the weight of ste was to start with wood cubic foot volume and convert to weight by multiplying the volume by density (mass per unit volume) using constant moisture content. This was not without problem because density and specific gravity can fluctu ate with geographic location (provenance), position in the tree, the proportion of early a late wood (which can be influenced by climatic variation), and site, especially altitude. Studies documenting density and specific gravit became very important, a good example of which Stage's (1963) work with lodgepole pine.

Subsequently, the problem became one of estimat ing tree or product weight directly from such measured tree variables as diameter and height. Pardé (1980) points this out as a classic probl in forestry: volume (weight) tables are require for each tree species. Thus, for a species, a sample of trees representative of the species population is selected, felled, and subsampled obtain fresh and dry tree weights. These weig are then related to the measured tree variables by some mathematical model. In some studies th stem sections, limbs, and foliage are weighed the field. Other studies weigh limbs and foli calculate stem volume from interval measuremen of diameter using taper functions or Smalian's

formula, and determine green and dry weights of stems from weighted average tree density and moisture content.

BIOMASS MODELING

A tremendous amount of research has addressed selecting the best mathematical models to fit sample data. The process is rigidly technical. For most models the independent variables used are diameter breast high (d.b.h.) or a combination of d.b.h. and height. Most researchers have found other measures, such as crown ratio, form class, age, site index, or stand basal area, add little to the accuracy of single-tree prediction, and some are difficult to obtain. An exception might be the prediction of crown, branch, or foliage weights where diameter at the crown base or crown length adds significantly to the accuracy of estimating these components.

D.b.h. alone is good for estimating biomass in an even-aged stand. But height, which is influenced by site, age, and diameter, is important in developing so-called generalized equations. These are equations developed where trees from many different site conditions are represented in a study.

Schlaegel (1982) provides a particularly good discussion of model selection and use. He reports it may be necessary to evaluate four basic models before making a choice for best fit. These are: the simple linear, the transformed allometric, the weighted linear, and nonlinear models. The biggest problem with the simple linear model is that the assumed condition of equal variance is often not satisfied if the range of the independent variable (usually d.b.h. or d.b.h. and height) is large. The problem of heterogeneous variance can be satisfied by using a weighted linear model in which the weighting may give a satisfactory minimum variance. An explanation of the procedures is given by Freese (1964).

The allometric model is probably the most widely used for biomass estimation. Although nonlinear, it can be fitted by least squares techniques through logarithmic transformation. This, however, presents the problem of interposing a bias into the process when the logarithmic predictions are converted back into arithmetic units. Crown weight is underestimated by 5 to 10 percent and bole weight by <1 to 2 percent. Baskerville (1972) has provided a method to correct for this bias and Beauchamp and others (1973a) have extended the work and have developed a computer program to compute unbiased allometric regression estimates (Beauchamp and others 1973b). Other nonlinear models can be fitted, but they take great skill in biometrics. Payandeh's (1981, 1983) papers provide excellent discussions of these problems.

Accuracy of most prediction equations varies by component. Usually those for the bole and total aboveground biomass are most accurate, having high coefficients of determination and low standard errors. The equations fit the data well and individual observations vary little from the mean. Live-crown predictions are often intermediate in accuracy, while dead-branch prediction is at best a good guess. Precision for these latter components can be increased when equations include an upper-bole measurement as one of the prediction parameters, such as diameter at one-third the height. Also, this may be a way to extend the use of an equation to locations beyond the area in which the sample trees were located. Many authors are now providing this capability.

Schlaegel's 1982 paper is particularly useful for the discussion of selection criteria to measure fit. He presents five statistics in addition to the commonly reported coefficient of determination (r^2) and the standard error of prediction ($S_{y.x}$) and shows how they can be used to compare models as well as choose the best one. An example is included in his paper on green ash volume and weight estimation (Schlaegel 1984). Also important is the development of confidence bounds for an estimate and the problems one faces in attempting to do this. Methods are available to calculate the confidence limit for each tree as well as the sum of any number of trees when simple or weighted linear models are used. But the author must provide the mean ($\bar{x}$) and the corrected sum of squares for the independent variable (x). In addition, approximation can be made for nonlinear models, but not all of the theory has been worked out for nonlinears.

STAND BIOMASS ESTIMATION

Perhaps the most important step is getting from the point of tree biomass to stand biomass. One way is to use the mean tree method, which requires an inventory to accurately determine the mean tree dimensions for the stand. For pure, even-aged stands the tree of mean basal area is best. Lacking a prediction equation to estimate weight, Pardé suggests 5 to 10 mean trees can be felled and weighed and the component mean biomass values determined. By multiplying these data for the mean trees by the total number of trees, the total stand biomass is obtained.

An alternative, when prediction equations are available, is to develop a stand table showing the number of trees by diameter class and total height and applying the prediction equation to obtain the results. A weight yield table, developed from the prediction equation, can be constructed for a variety of diameter and height classes or the equation can be solved for each tree in the stand or plot. For mixed stands, equations for each species are required.

Another method is to use stand basal area and the mean height of dominant and codominant trees as the prediction parameters (Faurot 1977; Schlaegel 1975; Alban and Laidly 1982).

Combining the work of several researchers to provide an estimate of total biomass may be a useful alternative. Hanley (1976) used this method in predicting biomass and productivity for grand

fir, western redcedar, and western hemlock habitats in northern Idaho. He used Stage's (1966) volume equation converted to weight by means of specific gravity for the stem wood estimate. Crown components were estimated from Brown's (1976) work in estimating forest fuels. For bark and roots it was necessary to consult regional work in progress by Faurot (1977) and Canadian data for some species--in all nine separate sources were used. By putting these all together Hanley arrived at an estimate of biomass. It may be possible, therefore, to make estimates to satisfy a particular tree component, species, or regional need if one is aware of the variety of sources of information.

Faurot's (1977) volume table work with ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), western larch (*Larix occidentalis*), and Douglas-fir (*Pseudotsuga menziesii*) in developing volume prediction equations has a good methodology section and allows estimating volume to a variable top diameter. Schlaegel (1973, 1978, 1984) provides a ratio-estimation technique for predicting weight and volume to various selected top diameters.

AVAILABLE LITERATURE: BIBLIOGRAPHIES

Biomass bibliographic studies began with Keays' (1971a,b,c,d,e) work published in five parts corresponding to commonly used tree components: unmerchantable top of bole, foliage, branches, crown and slash, and stump-root system. Another bibliography, by Art and Marks (1971), primarily deals with dry weight biomass and annual primary production studies, and Madgwick (1976) provided a reference on the methodology of mensuration. One should consult Cunia's (1979a, 1979b) papers for a summary of a survey on statistical methodology. In the early to mid-1970's Harold Young acted as a caretaker of biomass literature in his connection with the IUFRO working party on the mensuration of forest biomass. He tabulated studies by tree component (Young 1976), showing author, species, number of trees, units (whether metric or English), range of d.b.h. and height of study trees, the independent variables used in the prediction equations, and whether fresh or dry weight was included. Subsequently, Stanek and State (1978) supplemented the list primarily with Canadian species. Finally, Hitchcock and McDonnell (1979) added 137 new equations to complement Young's and Stanek and State's work. In 1979, H. A. I. Madgwick's personal bibliography on the subject was reported by Pardé to contain more than 1,000 titles. Tritton and Hornbeck (1982) provide an excellent source of biomass estimation equations for the Northeast covering 24 tree species. Other recent bibliographic works include Howe (1978), Hann and Riitters (1982), Baldwin (1982), and Satoo and Madgwick (1982).

APPLICATION

Problems and Precautions

Before applying a biomass equation one should check the range of sample tree locations. Although there have been many timber tree biomas studies in recent years, the resulting equations often have limited applicability because sample trees were selected to represent local conditions.

Some of the earlier work in developing biomass prediction equations for several tree components resulted in biomass tables for the various components that were inconsistent among themselves. Jacobs and Cunia (1980) provide a method of usi dummy variables to harmonize the function to allow similar shape and consistent spacing of th curves: when one tree component is part of a second tree component the regression estimates o the first must always be smaller than those of the second. Kozak (1970) also provides methods of ensuring additivity of biomass components by regression analysis. One should watch for the above inconsistency in using component equation Jacobs and Monteith (1981), in a conditional evaluation of equations for nine tree species that compared weight estimates from studies in Maine, New York, and West Virginia, found great similarity among trees of the same species in these widely scattered areas. Three species ha parallel and identical regression lines (equal slopes and intercepts); four exhibited parallel, but not identical lines (equal slopes but stati tically different intercepts). They suggest th regional weight tables are possible for some species.

Schlaegel (1975) found that volume estimates fo aspen (*Populus tremuloides*) agreed so closely t composite tables applicable for a number of Lak States species that the dry weight for aspen boles could be extended to other species after correcting for specific gravity differences. I the average stand wood specific gravity of the sample trees is provided by the author, one can develop a correction ratio by sampling for specific gravity in the stand of interest.

An example of the development of generalized equations is Alban and Laidly's (1982) work wit unthinned red and jack pine plantations in the Lake States. Twenty-nine jack pine and 28 red pine stands were selected to represent a broad range of age, site index, and basal area classe across the area. Regression coefficients or constants were developed to estimate nine tree components (foliage, live branches, dead branches, bole bark, bole wood, live crown, tot crown, stems, and whole trees) using nonlinear equations with d.b.h. and total height as the prediction parameters. Alban and Laidly also developed estimates of stand component weight using stand basal area (B) and mean height of dominant and codominant trees (H). They used a simple linear equation ($Y = a + b\ (B)(H)$) to obtain predictions that compared closely to results from summing individual tree estimates for all trees on the test plots.

Nutrient Cycling

Much interest in biomass estimation relates to nutrient cycling or nutrient content. Van Lear and others (1984) point out the latter is particularly important because of the potential impact of intensive silvicultural practices such as short rotations, whole tree harvesting, and certain site preparation methods on the nutrient status and productivity of forest sites. They feel that using prediction equations to estimate biomass of tree components from tree diameter is preferable to using an average tree approach because the proportions of foliage, branches, bark, and wood change with tree size (Jokela and others 1981). In their study of loblolly pine plantations in South Carolina, Van Lear and others found crown biomass (limbs, foliage, and top above 5 inches) represented 20 percent of the above-stump biomass but contained 49 percent of the nitrogen, 45 percent of the phosphorus, 37 percent of the potassium, and 36 percent of the calcium. Also, to determine concentrations of nutrient elements in a stand it would be best to calculate stand component biomass from generalized prediction equations and determine nutrient levels by sampling in the stand of interest rather than using nutrient prediction equations directly. Nutrient concentrations in biomass may vary considerably from site to site while biomass equations are less site specific. The weighted nutrient concentrations determined from the sample multiplied by the predicted dry weights would then provide an estimate of the stand nutrient pool content.

FOREST SURVEY PROGRAM

A major national effort to estimate biomass was initiated in January 1980 with the formation of the National Tree Biomass Compilation Committee. This committee consisted of individuals from Resources Evaluation Projects in the North Central, Northeastern, Southeastern, Southern, Intermountain, and Pacific Northwest Stations and a representative from the Forest Products Laboratory in Madison. The first phase of their work was a national biomass compilation using state-of-the-art methods available to the individual research work units. This resulted in the publication "Tree Biomass" (USDA Forest Service 1981), which estimates the green weight of aboveground tree biomass on commercial forest land by a variety of regions, sections, species groups, and owner classes. The second phase was to identify research needs that surfaced in trying to assemble and apply available prediction equations and methods to accomplish phase 1. However, not much has happened as a result of this analysis. The third phase was to promote the integration of biomass estimation into the ongoing resources evaluation inventory system to make State-by-State analyses of biomass availability, and to assess the competition that might develop between fuel and fiber uses of biomass.

The effort in phase 1 was hampered by lack of information regarding the amount of wood and bark in the whole tree, particularly the crown, and the lack of specific equations for many tree species. In the Lake States, Rocky Mountain, and Pacific Coast regions, merchantable bole volume estimates from survey were converted to weight using available wood-density data. Then conversion factors were used to estimate bark, top, and limb weight as a ratio of bole weight. In the East and Alaska, tree-weight equations were available to apply to stand tables developed in the State-wide forest inventories enabling an individual-tree approach to estimate biomass.

In addition to the national report, regional reports were produced. An example is "Whole Tree Volume Estimates for the Rocky Mountain States" (Van Hooser and Chojnacky 1983). They present the wood-density and bark-to-wood ratios used to convert volume to weight and the equations to estimate bark, top, and branch weight. Although the regression parameters and constants developed provide somewhat imprecise estimates, they do provide a methodology to allow reasonable prediction of biomass on a State-wide basis. The authors point out that, by manipulating the tabulated data, several additional factors can be developed and used to divide existing resource estimates. For example, the biomass of tops and limbs from harvested trees can be estimated from timber removal data. Van Hooser and Chojnacky estimate that the percentage of total biomass in small trees, cull trees, and tops and limbs of growing stock trees is 34 percent of total biomass in the region.

These early regional reports are limited to material on commercial forest land. A further extension has been for Forest Inventory and Analysis (FIA) research projects to collect information to assess biomass on noncommercial and nonforest land, and to include shrubs and herbaceous vegetation--the whole ball of wax so to speak. An example is the multiresource inventories in the Southeast. Cost (1978) and Cost and McClure (1982) published papers detailing the methodology for developing State-wide biomass inventories. Of most interest may be the models developed to quantify the biomass of non-growing-stock trees as well as seedlings, shrubs, vines, grasses, and forbs--all important from the wildlife management standpoint and perhaps the nutrient pool analysis.

Cost and McClure developed four programs to process the data. The first converts merchantable volume to weight. The second tabulates number of trees, merchantable green weight, biomass green weight, and biomass component weight. The third converts cubic feet of space occupied by understory vegetation on commercial forest land to weight and shows per-acre weights for seedlings, shrubs, vines, grasses, and forbs. The fourth provides 13 biomass tables showing similar data for nonforest areas.

In March 1984, a Forest Land Inventory Workshop was held in Denver with the theme "Preparing for the 21st Century," intended, in part, to promote techniques exchange among Forest Service Regions and Stations as a means to improve the kind and

quality of inventory data (Lund 1984). Because FIA research projects now include an estimate of forest biomass in inventories, I expected to find how this was being done in the various Stations. Only the Southeastern Station highlighted their effort to measure timber tree biomass including stumps, limbs, and tops of trees 5.0 inches d.b.h. and larger. Intermountain explained their use of visual segmentation to estimate volume of "other species," primarily pinyon (Pinus edalis) and juniper (Juniper L.) and all other hardwoods except cottonwood (Populus L.) and aspen in woodland types. Most simply mentioned that an estimate of biomass was included in current assessments. The impression from reviewing the proceedings was that developing better biomass estimation methods was not a high-priority problem in most areas, even though somewhat crude methods are now used in the estimation process.

CONCLUSIONS

A major problem in estimating timber tree biomass is the lack of suitable equations for many species. There are very few generalized equations that can be used to cover an entire region, area, or species mix with which one might be working. As the Stations continue to include biomass as a part of State-wide forest surveys, I expect the voids for important timber species in the various regions will be filled through the development of additional prediction equations. Until then, however, piecemeal approaches will have to be used.

The potential to regionalize existing equations should be investigated. Several researchers have had encouraging results in comparing prediction equations for certain species from widely separated sample areas. Also, it may be possible to develop conversion factors or ratios to extend equations to similar species or other areas with a minimum of expense in destructive sampling and field weighing.

I have compiled a bibliography of publications on tree biomass prediction containing more than 325 entries. Copies may be obtained by writing to me.

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BIOMASS DETERMINATION OF NONTIMBER SPECIES OF PLANTS

Peter F. Ffolliott

ABSTRACT: With increasing demands for alternative energy sources, better means of determining quantities of biomass that are potentially available for energy use are needed. This need is especially apparent for nontimber species of plants, for which "standardized" mensurational techniques are incomplete and for which methods are more or less developed in response to local needs.

INTRODUCTION

Throughout the world, demands for biomass as an energy source are increasing. Many households, and even whole communities in the Third World, depend entirely on biomass, often derived from woody plant species, for cooking and heating (Boyce 1979). With these increasing demands, better methods of determining biomass quantities of woody plants that are potentially available for use are needed. In particular, this need is apparent for nontimber tree species and woody shrubs, for which mensurational techniques are frequently incomplete.

In many instances, there are no "standardized" mensurational techniques to determine biomass quantities of nontimber species of plants. Rather, methods are more or less developed in response to immediate needs in a particular locale. Because, however, nontimber tree species and woody shrubs are almost by definition of lesser value than commercial timber resources, it is not uncommon for only limited funding and time to be allocated to their assessment. Nevertheless, the determination of nontimber biomass can be a critically important mensurational undertaking.

Over the past several years, I have had several opportunities to work with mensurationists and inventory specialists in the United States and around the world in attempting to quantify the biomass of nontimber tree species and woody shrubs that might be available for subsequent energy use. Evolving from these opportunities has been a collection of "methodologies," some of which I would like to describe in this paper; for the most part, these are not innovative methods but applications of known approaches to meet specific needs.

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For purposes of discussion, I would like to define nontimber biomass as that derived from trees and woody shrubs having little value for primary wood products (for example, lumber, veneer, poles). Determination of biomass for timber species of commercial value has been discussed in a previous paper.

In this discussion of biomass determination for nontimber species of plants, three main topics will be mentioned: primary sampling designs, selection of trees and woody shrubs for measurement, and individual tree and woody shrub measurements. Major emphasis will be placed on individual tree and woody shrub measurements that are used to estimate biomass, however.

PRIMARY SAMPLING DESIGNS

Nearly any and almost all primary sampling designs can be or are used to measure nontimber biomass. Only rarely are complete enumerations of populations justified, but simple and stratified random sampling designs, and numerous combinations thereof, have all been employed at one time or another. In many Third World countries, where statistical integrity may be less rigid, systematic sampling designs are also used. Frequently, measurements of nontimber biomass are "piggy-backed" onto primary sampling designs that are utilized to inventory other natural resources, such as commercial timber, forage, or soil.

Occasionally, interpretations of aerial photography and ground measurements are coupled in various two-stage sampling designs to measure nontimber biomass. Again, many options exist, but the combinations that are chosen to select trees and woody shrubs for measurement must be consistent with stated goals of the biomass inventory.

In general, any design that meets the sampling objective can be used as the "vehicle" for obtaining measurements required to quantify nontimber biomass. Of course, the reliability of estimates drawn from the measurements of biomass largely depends upon the sampling procedure and intensity.

SELECTION OF TREES AND WOODY SHRUBS FOR MEASUREMENT

Nontimber tree species and woody shrubs can be selected for measurement through implementation of three general theories of sampling probability: probability of selection proportional to frequency, probability of selection proportional to size,

and, in a few cases, probability of selection proportional to prediction (3P). Most commonly, fixed-area plots or point sampling techniques are employed. Nontimber species of plants have been selected for measurement by 3P methods in a few instances, however.

INDIVIDUAL TREE AND WOODY SHRUB MEASUREMENTS

The individual tree and woody shrub measurements taken depend, in large part, upon the purpose of the nontimber biomass determination. In general, tree and woody shrub biomass can be quantified in terms of volume (cubic meters, cubic feet, cords); weight (kilograms, metric tons, pounds); or potential energy equivalents (kilojoules, Btu's, calories). Estimation of volume is frequently, however, the most difficult mensurational task.

Approaches that are considered in estimating the volume of nontimber tree species are presented below. Only rarely is the volume of woody shrubs estimated through plant measurements. To provide a reference point in this discussion, the unit of volume is cubic meters, although in principle, the remarks are independent of volume unit.

Individual Tree Measurements

In taking the measurements, two general tree forms, differentiated by types of branching, are often recognized: excurrent and deliquescent. In general, trees possessing a terminal leader, whose growth is prolonged to form an undivided main bole, are considered to be excurrent. Trees whose main bole is not so evident, but instead divides into a number of limbs, are said to be deliquescent. There are a number of variations within these general tree forms, however, so the following remarks should be broadly interpreted.

Excurrent Form

Trees characterized by an excurrent form are relatively easy to measure, as every forester worth his or her salt knows. One simply tallies by tree species (to identify the appropriate specific gravity value for determination of weight and potential energy equivalents), d.b.h., and for a subsample, height. When available, volume tables are then interpreted to obtain estimates of tree bolewood volumes. Unfortunately, volume tables are not always available to estimate the volume of nontimber species. In these instances, "rule of thumb" relationships, as presented below, are frequently employed:

$$\text{VOLUME (CUBIC METERS)} = \frac{\text{DBH (CENTIMETERS)}^2 \times \text{HEIGHT (METERS)}}{3} \times 10^{-4}$$

This equation is a "composite" expression of volume that has been derived from measurements of over 50 nontimber tree species in the United States and around the world. Testing to date suggests that solutions of the equation are reliable estimates of volume; however, it is important to remember that this equation is but a rule of thumb to be applied only in the absence of standard volume tables.

From the above, estimates of volume in tree bolewood are obtained. To expand these estimates to estimates of the total tree volume (including branches, twigs, and so on), various empirical relationships from the literature are extrapolated whenever possible, to represent the conditions sampled. (A synthesis of the literature [Hitchcock and McDonnell 1979] suggests that softwood species have 15 to 20 percent of the total tree biomass in crown wood and leaves, whereas hardwood species have approximately 20 to 25 percent of the total tree biomass in crown wood and leaves.) Although these relationships may not directly apply to the particular nontimber tree species being measured, their use, in many cases, provides reasonable estimates of total volume of tree biomass from available inventory data.

Single-stemmed and multistemmed trees of excurrent form are measured as outlined above. When multistemmed trees branch at ground line or below d.b.h., the individual stems are considered to be single-stemmed. When, however, multistemmed trees branch above d.b.h., they are usually considered to be deliquescent in form, and individual tree measurements are taken accordingly.

Deliquescent Form

Trees that exhibit a deliquescent form are more difficult to measure and quantify than trees of excurrent form. When confronted with a deliquescent tree form, two questions arise almost immediately. What diameter and height measurements do we measure? How is volume estimated from these measurements? These questions cannot be easily answered. In attempting to do so, a forester often takes the liberty of discarding "traditional" measurements (such as d.b.h.) and replacing them with individual tree measurements; these are frequently based on destructive sampling and relate to the total volume of tree biomass.

Destructive sampling of nontimber tree species is conducted to define, if possible, predictive equations between the total volume of tree biomass and individual tree measurements that are easily obtained without bias. In my experience with studies of this kind (involving neem in the West Africa Sahel, the genus Prosopis in the subcontinent of India, the genus Acacia in the dry zones of Chile and Peru, and oak in the Southwestern United States), trees selected for destructive sampling are initially measured in a range of diameters, heights, and lengths, all of which can be incorporated into an inventory of nontimber biomass. The trees are then felled and cut into pieces of wood that in general correspond to local utilization practices. From these data, predictive equations are derived if statistically possible.

The results of the destructive sampling investigations cannot be generalized because the findings are too inconsistent. In some instances, statistically reliable predictive equations have been obtained to estimate the total volume of tree biomass. When this happens, the individual tree measurements specified are taken to directly solve the equations. In other cases, however, reliable predictive equations cannot be developed to any degree of accuracy. Instead, only "hints" as to the individual tree measurements that might "index" the total volume of tree biomass are discovered; for example:

1. Basal diameters (at ground line) can be a better predictor of volume than diameter measurements taken at breast height.
2. Total height measurements can serve as a predictor of volume, particularly in even-aged, human-made forests of uniform height.
3. The number of trees can also be used to predict volume, especially when this measurement is combined with diameter size and frequency distribution.

One final comment regarding the destructive sampling investigations is warranted. The preferred expression of tree biomass is frequently by weight and, ultimately, potential energy equivalents. When this is so, weighing the pieces of wood, rather than attempting to estimate volume and then converting to weight by multiplying volume by specific gravity values, may be the best approach.

From measurements of weight, potential energy equivalents are readily derived by multiplying weight by appropriate heat contents, the latter values being obtained from calorimetric measurements in the laboratory or the literature (table 1). Also, measurements of weight can often be related to individual tree measurements in predictive equations which, subsequently, are used to inventory tree biomass in terms of weight. This general approach can also be employed to measure the biomass of trees with excurrent form and, as discussed below, woody shrubs.

Table 1.--Heat of combustion values for selected nontimber tree species in the Southwestern United States (Voorhies and Huntsberger 1983)

Common name	Heat of combustion	Specific gravity
	Btu's/lb	
Arizona cypress	9,292	0.65
Arizona walnut	8,571	.59
Juniper, alligator	9,050	.45
one-seed	9,212	.57
Utah	9,394	.51
Mesquite	8,657	.70
Oak, Arizona white	8,038	.71
Emory	8,420	.64
Gambel	8,182	.63
Pinyon	8,913	.51

Individual Woody Shrub Measurements

The easiest and, perhaps, in general the most common, method of estimating the biomass of woody shrubs is through weight measurements. The complex forms of growth that inherently characterize woody shrubs preclude in most instances accurate estimates of volume. Therefore, through destructive sampling, weight is related to individual woody shrub measurements (height, crown form and relative size, foliated area). The resultant predictive equations are then used to convert inventory measurements of woody shrubs to weight, with later conversion to potential energy equivalents (as outlined above), if required.

FUTURE NEEDS

From my personal experiences in attempting to quantify nontimber biomass, various mensurational research needs can be recognized. Among the more important of these are:

1. Cost-efficient sampling designs to determine nontimber biomass on a large-scale basis for operational evaluations.
2. Improved volume tables that describe more representative biomass volumes of nontimber tree species.
3. Identification of variations in specific gravity values for different portions and components of trees and woody shrubs.
4. Reliable equations for predicting weights for trees of deliquescent form and woody shrubs of complex growth forms.
5. More species-specific estimates of heat content values to determine potential energy equivalents.

At least partially satisfying these and other research needs should greatly enhance a forester's ability to quantify nontimber biomass for energy use in the future. With increasing demands for energy of all sources, these quantifications will be imperative in the future.

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VOLUME AND BIOMASS ON GAMBEL OAK WOODLANDS

Kendall L. Johnson

ABSTRACT: Recent use of Gambel oak has been based on the attitude that it is a "nuisance" species, to be controlled as a means to increase forage production and improve tree regeneration. Now interest has arisen in oak as a fuelwood resource, underscoring the lack of management information on the type. Recent studies on Gambel oak have provided information on volume and biomass, which indicate that (1) there is sufficient stem biomass available to make Gambel oak an important fuelwood resource, (2) productivity is probably high enough to exceed economic thresholds, (3) inherent sprouting is ideal for a fuelwood management cycle, and (4) fuelwood values should be included in all management plans where Gambel oak is a component of the habitat.

INTRODUCTION

It is appropriate, yet symptomatic, for a practical range manager in a regional technical conference peopled by research foresters, biometricians, and mensurationists to address the subject of volume and biomass of Gambel oak (Quercus gambelii) woodlands. It is appropriate because Gambel oak lies at the interface between forest and range as kinds of land. Hence the ecology and productivity of the vegetation associated with Gambel oak are the legitimate concern of the range manager. The involvement is symptomatic of changing attitudes as well, because until recently range managers have dealt with the type by default: foresters have not considered Gambel oak a true wood resource but just another woody plant. Clonal species, which are as often shrubs as they are small, irregular trees, have not been of concern. In the absence of real value in the wood resource itself, aided by the indifferent forage value of the shrub (as opposed to the vegetative type), the idea developed that Gambel oak is a "nuisance" species with few redeeming values. Thus it has fallen to the range manager to set management priorities concerning it.

It should not be surprising that the hallmark of Gambel oak management to date has been its reduction or elimination as a means to increase forage production. So in a land of difficult resource use, a prominent resource has received only negative attention. Although the situation is changing, with new interest and management emphases developing, everyone interested in Gambel oak shares a common problem: the information base is extremely shallow.

A QUICK NATURAL HISTORY

Gambel oak occurs in the Four Corners States of Utah, Arizona, New Mexico, and Colorado as a dominant overstory on about 9 million acres (fig. 1) (Tiedmann and others 1983).

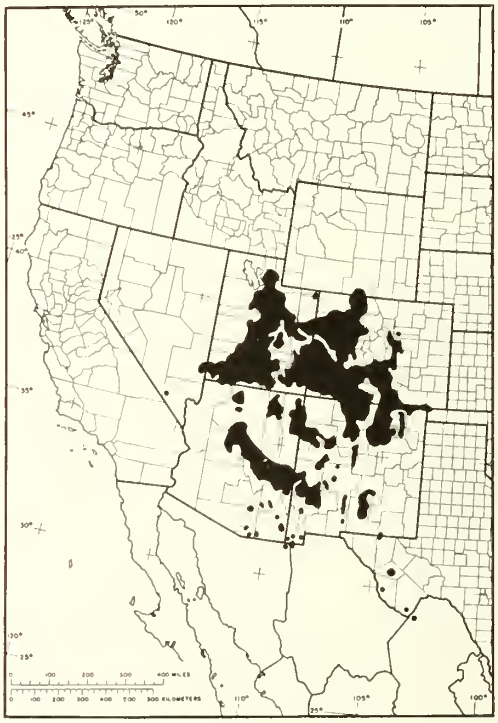

Figure 1.--Distribution of Gambel oak (Little 1971).

Its growth form is normally a multiple-stemmed clone varying from a small shrub (fig. 2) to a medium-size tree. On deeper, better-watered soils, oak can achieve a full tree form (fig. 3); the incidence of tree sizes increases with distanc south in its range (Reynolds and others 1970; Barger and Ffolliott 1972). Wullstein and Neilson (1985) asserted that successful sexual reproduction of Gambel oak in northern Utah is rare, due to late spring freezes, acorn predation, and summer drought stress of seedlings. Thus Gambel oak in its northern ranges may be an artifact of an earlier, more mesic climate,

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Paper based on an address presented at: Growth and Yield and Other Mensurational Tricks: A Regional Technical Conference, Logan, UT, November 6-7, 1984.

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sustained solely by its capacity for vegetative reproduction. This relation helps explain the preponderence of larger sizes in the southern ranges.

Figure 2.--Growth forms of Gambel oak; usual multiple-stemmed shrub.

Figure 3.--Growth forms of Gambel oak; occasional full tree form.

The Gambel oak type provides good winter habitat for mule deer, due to its high cover potential and plentiful acorn production. They also browse new growth and sprouts created by fire or harvest. The type is also a good livestock resource due to associated forage species. Oak itself is of only fair to poor value, and young shoots contain significant amounts of tannic acid. Poisoning, especially of cattle in the spring, is possible under conditions of heavy intake (Muenscher 1961).

The early Utah settlers used Gambel oak and other woody foothill species for fuel and fence posts. Oak soon proved to be poor fencing material, but it had superior heat-producing qualities as fuelwood (18 percent > pinyon; 24 percent > juniper) (Clary and Tiedmann 1985). This attribute ensured continuous use in the first decades of settlement, declining in later years as alternate fuels became available. Use of oak as fuelwood virtually disappeared in post-World War II years, and the species settled into its "nuisance" status for most of two decades, to be removed if possible, discouraged if not, or simply ignored.

The energy crises of the past decade have revived interest in oak as a fuelwood resource, intensified by its proximity to population centers. As a consequence, interest in management of the species as a renewable resource has also surfaced, as pointed out by Winward (1985).

THE PRESENT SITUATION

In contrast to other tree and shrub types of the Intermountain West, little is known of Gambel oak. Ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea Engelmannii*), and other species of the montane zone join pinyon-juniper (*Pinus edulis* and *Juniperous osteosperma*) as focal points of extensive bodies of literature. By contrast, the literature on Gambel oak is scant and readily plumbed. Relatively little is known about its physiology or ecology, nor even the extent or productivity of the resource. Virtually nothing is known about stand management. More is known about methods of removing Gambel oak (Parker and Ritty 1982) than about its biological status. As a consequence, Gambel oak fully merits A. R. Tiedemann's apt description, the "forgotten resource of the Intermountain West."

Recognizing the situation, the Shrub Sciences Laboratory of the Intermountain Research Station has initiated a research program. Efforts to develop an information base about Gambel oak physiology, ecology, and aspects of management are proceeding and include studies on stem and stand characters.

MEASUREMENTS OF OAK VOLUMES

Of most interest to this conference will be estimation techniques to derive volume and biomass of Gambel oak. Van Hooser and Schaefer (1985) observed that the traditional methods employed to define volumes of timber species cannot be employed on clonal species such as Gambel oak for a simple reason: lack of a well-defined central stem. This fact, combined with the low intrinsic value of the species, has forestalled direct measurements of volume and

derivation of estimation techniques. A recent study conducted in north-central Utah by Clary and Tiedemann (1985), however, has provided direct information on oak volumes and biomass.

Intensive sampling of eight plots of variable dimensions for all biomass above and below ground (live and dead) showed that stem density ranged from 2,000 to 14,000 stems per occupied acre, and that density was significantly related to stand height, but not to age, which suggests a genetic determination. Most individual clones occupied much less space than an acre at 30 to 300-ft spacing.

Biomass distribution per occupied area, derived from expansion of plot data, indicated that total live biomass approximated 111,000 lb/acre, made up of overstory stems (33 percent), branches and leaves (5 percent), underground roots, rhizomes, and lignotubers (56 percent), and associated plants (6 percent). Dead biomass totalled about 53,500 lb/acre, consisting of dead branches on live stems (15 percent), standing and down stems (23 percent), and dropped foliage and other litter (62 percent). The ratio of live to dead biomass on the study sites was 67:33; that of above- to below-ground biomass, 44:56.

Clary and Tiedmann (1985) compared these results with similar values derived from other woodlands. They found that the live above-ground biomass of approximately 24 tons/acre placed Gambel oak within the lower values found among interior West commercial forests (22-133 tons/acre) determined by Weaver and Forcella (1977). The placement was similar when only living overstory biomass was considered: 21 tons/acre. But Gambel oak differs in one significant characteristic: ratio of above- to below-ground biomass. The value of 44:56 was distinctly at variance with the mean values (83:17) of oak stands around the world reported by Santantonio and others (1977) or for other western semiarid oaks (65:35) noted by Whittaker and Niering (1975). Clary and Tiedemann (1985) suggested that the massive underground system of lignotubers, roots, and rhizomes of Gambel oak creates the difference.

Based on these data, Clary and Tiedemann (in press) developed prediction equations for stem biomass components in the relation:

$$\log Y = a + b \log X$$

where

Y = weight of ovendry biomass

X = basal stem diameter

a,b = regression coefficients

A set of graphic curves was developed from the relation to provide land managers estimates of bole biomass from the single measurement of basal diameter.

A method developed by the Forest Survey Unit of the Intermountain Station relates volume to tree attributes that are readily measurable (Van Hoose and Schaefer 1985). The technique, called visual segmentation, is based on measurement of lengths and midpoint diameters of all uniform segments (visually defined) of stems and branches within size classes, usually 2-ft lengths and 2-inch diameters. Tree volume is then developed by summing the individual segments. Regression analysis of plot data yielded the equation:

$$V = a(D^2H)^b$$

where

V = volume in cubic feet

D = basal diameter in inches (outside bark

H = height in feet

a,b = regression coefficients

Tests of the visual segmentation technique on species with irregular stems such as juniper have established that it produces reliable estimates of volume. Extension of the technique to a clonal species like Gambel oak will require clonal attributes in the relation, that is, average stem diameter and height, stem density, and clone basal area. To date this has not been done; hence there is no readily usable method of estimating Gambel oak volumes on a survey basis.

THE FUELWOOD RESOURCE

Applying biomass estimates to Gambel oak stands yields a first approximation of fuelwood values. On the basis of their study, Clary and Tiedemann (1985) estimated that bole wood volumes ranged from 7 to 14 cords per acre. In a study of the economics of using Gambel oak for fuelwood, Wagstaff (1985) found that minimum harvest size (set at 3.5 inches diameter) was reached in about 65 years among clones of oak at six locations in north-central Utah. The annual increment of growth declined rapidly at younger ages and leveled out at about 2 percent annually after minimum harvest size was reached. Based on current retail prices of oak firewood and estimated costs of harvesting, Wagstaff (1985) found that stumpage prices of oak clones ranged from \$115 to \$2,300 per stocked acre. These values indicated that Gambel oak can be successfully managed for fuelwood where markets exist and competitive uses of land are limited. The economic value of the standing crop of wood is significant. Studies conducted by Tiedemann and others (1983) indicate a value of approximately one billion dollars if 10 percent of the habitat could be managed for fuelwood production. Use of Gambel oak lands as wood-producing sites may well be more valuable than any other use.

CONCLUSIONS

Although the wood resource represented by the Gambel oak type of the Intermountain West remains poorly defined, enough information is at hand to

draw the conclusions that (1) there is sufficient stem biomass available to make Gambel oak an important fuelwood, (2) productivity is probably high enough to exceed economic thresholds, (3) its profuse sprouting is ideal for a fuelwood management cycle, and (4) fuelwood values should be included in all management plans.

The Gambel oak type will continue to provide an important forage resource for livestock and big game, but in an age of increased pressure on natural resources within a heightened environmental awareness, concentration on single values is no longer appropriate. Gambel oak has high potential to produce fuelwood, forage, and wildlife habitat values concurrently, requiring a high degree of cooperation and coordination in developing appropriate management plans.

Too little information, especially on stand management techniques, is available to achieve true multiple-use management immediately or even soon, but Gambel oak is ready to take its place among interior West resource values. Range managers invite foresters generally, and mensurationists particularly, to help define that place. The "forgotten resource" has been discovered.

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FOREST METRICS: ARE WE THERE? WHERE DO WE GO FROM HERE?

James D. Arney

ABSTRACT: Comments on state of the art in forest mensuration focus on sampling and growth modeling. In the area of sampling, discussion emphasizes standing inventory, growth and mortality, site productivity, and stem volume. Growth modeling is discussed in the context of demands by users for yield information and in the context of the kind and amount of data available to develop these models. Recommendations are based on input from presentations in this conference.

INTRODUCTION

The views presented over the last 2 days make it clear what is possible in the development and implementation of mensurational technology; however, varying approaches, budgets, and objectives have meant that not all of us are applying the same methods. This is as it should be. We have also recognized these last 2 days that most of us are not where we would like to be.

In this presentation, I would like to identify the mensurational techniques that offer the most promise for getting us to where we could be. The discussion of sampling and growth modeling techniques will be followed by a list of my recommendations on where we go from here.

SAMPLING

In sampling for standing inventory and for growth ("change"), our needs are evolving and becoming more specific. The continuous forest inventory (CFI) plot designs are no longer adequate, and we are moving toward computer-based geographic information systems with specific details about the character of each stand in the inventory. Figure 1 illustrates the detail now required for each stand. Our harvest scheduling and silvicultural planning activities demand knowledge of species mixes, size distributions, merchantable yields, defect reductions, stand vigor and health, stand density, age, distance to mill, logging operability, and season of access.

These details are most efficiently obtained by sampling within stands using temporary variable-density plots. Measurements must be included for height and crown ratio within tallied diameter classes by species. Stands are typically 10 to 300 acres and are resampled on a 5 to 10 year schedule. Intermediate inventory reports are provided using growth model updates. Sampling for inventory data bases includes all commercial species in the stand without regard to current merchantable dimensional limits. Permanent plots and growth from increment cores are not cost effective in sampling for stand-based inventories.

PACIFIC NW REGION — OPERATING UNIT
FOREST YIELD REPORT — RESOURCE INVENTORY SYSTEM (RIS) — STAND NUMBER 237
TOTAL ACRES 132 — SITE INDEX 870
TIMBER TYPE WHDF — TOTAL AGE (YRS) 9
EXAMPLE REPORT FOR UTAH CONFERENCE

BH SP AGE	DBH	TREES /ACRE	BASAL AREA	HEIGHT	CROWN RATIO	TOTAL CUFT	MERCH CUFT	MERCH BDFT	NET BDFT	#LOGS /MBF	LO OI
				** VALUES ON A PER ACRE BASIS **							
	8	2	0.7	93.0	47	29	0	0	0	0	
	9	5	2.1	100.1	51	90	0	0	0	0	
	11	37	25.6	107.1	54	1144	1070	5503	5118	33.0	8.
	14	46	46.9	107.6	54	2099	2010	11040	10267	22.0	9.
DF 80	12.3	90	75.3	107.6	54	3362	3080	16543	15385	25.7	9.
	10	34	16.9	106.8	67	767	687	3400	2822	40.3	7.
	13	120	102.4	112.3	69	4881	4619	25036	20780	23.5	9.
	15	41	50.2	114.2	69	2433	2340	12710	10549	17.2	10.
WH 81	12.5	195	169.6	114.2	69	8081	7646	41146	34151	22.9	9.
ALL	12.4	285	244.9	111.9	64	11443	10727	57689	49536	23.7	9.

CCF=397 STUMP HT. 1.0 LOG LENGTH 16.4 TOP DIB 5.0 MIN DBH 9.0

Figure 1.--Example inventory report for 90-year-old stand.

We sample for growth and mortality in order to assign portions of the change that occurs from one inventory measurement to the next to different components of growth, ingrowth, growth on mortality, and mortality. Plots are permanently located, either fixed-area or variable in design, all trees are tagged, and measurements minimally include diameter at breast height (d.b.h.), tree height, crown ratio, and species. As seen in figure 2, volume change for the measurement interval may be defined into survivor growth, growth on mortality, ingrowth, and loss due to mortality. Distribution of these permanent growth plots is independent of the standing inventory samples described earlier, and the objectives are very different. These permanent plots must provide a data base that equally represents all species across all site productivity classes for the range of stand densities and size distributions that currently exist or that managers are moving toward. This data base

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Paper presented at: Growth and Yield and Other Mensurational Tricks: A Regional Technical Conference, Logan, UT, November 6-7, 1984.

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is the basis upon which the growth update model is developed.

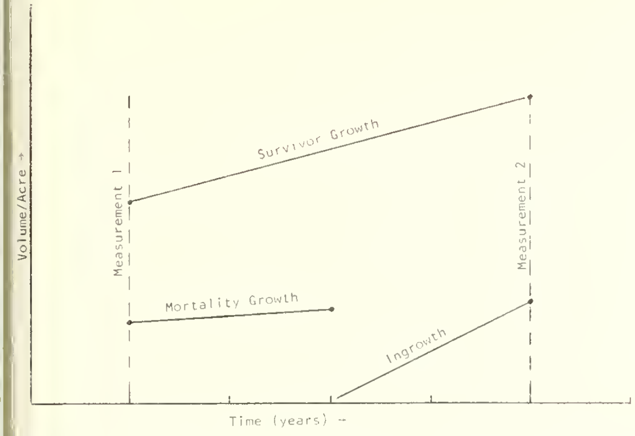

Figure 2.--Components of change from growth trend studies.

In sampling for site productivity, we require another geographic stratification independent of the forest inventory discussed earlier, and again a geographic information system is heavily utilized. Productivity has been stratified by standing volume, growth, site index, and habitat in this region. My experience has been that we place the greatest confidence on a field-observable index that is easily and repeatedly obtainable by different observers. Tree site index is the site productivity index of choice. To be used effectively, the base reference age for all species in the West should be converted to 50 years measured at breast height. We are not managing stands to rotations of 100 years or longer; therefore, a 100-year base is no longer observable. Costly stem analyses are not needed if we apply Boris Zeide's (1978) growth type concept (fig. 3). I recommend field measurements

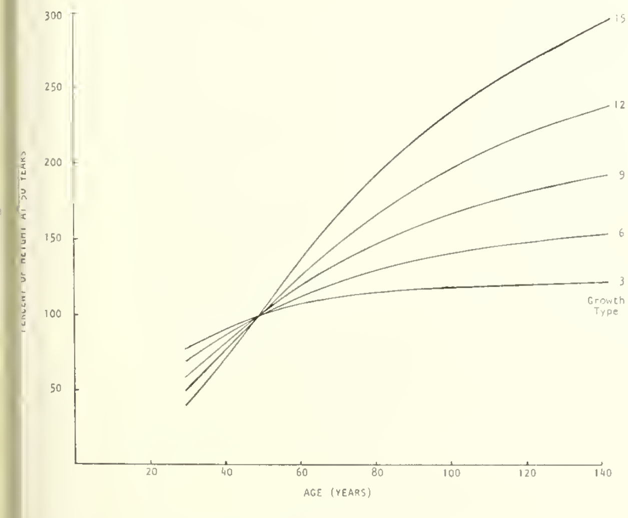

Figure 3.--Shape of height growth types.

of total height above breast height at 30 and 60 years on at least three trees for each species at each sampling location. Height at 50 years from the growth type curve is the reference site index. Differences in site index among species at the same location are used in the growth projection model to drive species-specific growth equations. Currently available site index curves for major species in the West have a range of growth types as displayed in figure 4.

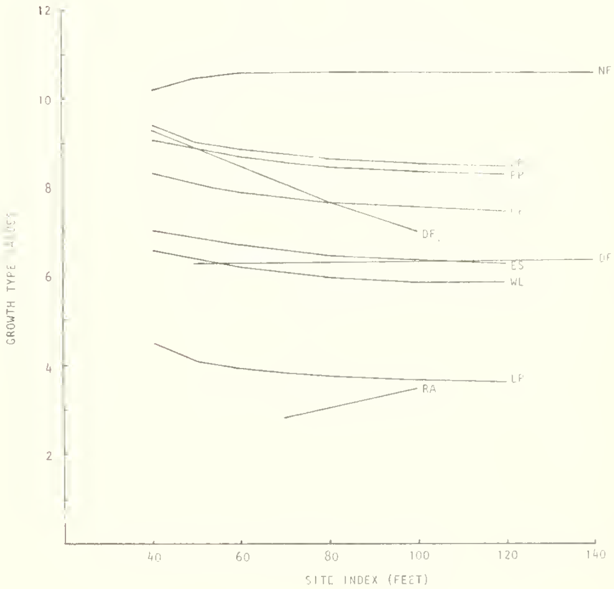

Figure 4.--Trends in growth types for published site curves.

Since not all of our lands have healthy, free-growing 60-year-old trees on them, a number of other soil and climate parameters should be recorded at each site-tree measurement location. These parameters should include annual precipitation, elevation, aspect, slope, soil depth, and soil parent material. Strong correlations have been found between these parameters and site index. An index of site productivity may then be assigned to all stands in the inventory regardless of their age or vigor. In addition to providing an effective means of estimating site index, these parameters have been found to be correlated with the growth type values. This provides not only a location-specific productivity index, but also a location-specific growth shape index for the yield projection of each stand.

It is apparent that our silvicultural planning activities are much more demanding of an inventory data base than ever before. One more sample design is needed, that is for the development of taper equations for all commercial species. Hardly a month goes by that inventory and yield projection reports are not generated for at least two alternative merchantability specifications. Whole tree volume equations and tariff tables are no longer adequate. The whole

bole taper equation system by Damaerschalk and Kozak (1977) works well and has been fit to 16 species in British Columbia.

GROWTH MODELS

Our demands on growth models have changed in recent years. As with the standing inventory report, we need clear descriptions of species mixes, size distributions, merchantable yields, defect distribution, stand vigor, and stand density (fig. 5). Growth models must provide stand table distributions and taper functions by species. Growth functions must perform in a stable manner at any age, density, or treatment. Stand average models are no longer sufficient.

PACIFIC NW REGION — FOREST YIELD REPORT — VERSION 84.01 — STAND PROJECTION SYSTEM (SPS) — SITE INDEX 87 DF — BASE- 50 YRS BH AGE — TOTAL AGE YRS 90

EXAMPLE REPORT FOR UTAH CONFERENCE

SP	BH AGE	DBH	TREES /ACRE	BASAL AREA	HEIGHT	CROWN RATIO	TOTAL CUFT	MERCH CUFT	MERCH BDFT	NET BDFT	#LOGS /MBF	LOG DIB
				** VALUES ON A PER ACRE BASIS **								
		8	2	0.7	93.0	47	29	[illegible]	[illegible]	0	0	0
		9	5	2.1	100.1	51	90	[illegible]	[illegible]	0	[illegible]	0
		11	37	25.6	107.1	54	1144	[illegible]	[illegible]	5118	33.0	8.1
		14	46	46.9	[illegible]	54	2099	2013	11940	10267	22.0	9.6
DF	8[illegible]	12.3	90	75.2	[illegible]	54	3362	3080	16547	15385	25.7	9.[illegible]
		10	34	16.9	106.8	57	767	687	3400	2822	41.3	7.5
		13	120	102.4	112.3	69	4881	4619	25036	2078	23.5	9.4
		15	41	5[illegible].2	114.2	69	2433	2340	12710	10549	17.2	10.9
WH	81	12.5	195	169.6	114.2	69	8081	7646	41146	34151	22.9	9.5
ALL		12.4	285	244.5	111.9	64	11443	10727	57689	49536	23.7	9.4

CCF=397 STUMP HT. 1.0 LOG LENGTH 16.4 TOP DIB 5.0 MIN DBH 9.0

Figure 5.--Example yield table report for a 90-year-old stand.

The tree-list model is easier to develop and is more robust than a stand model. We have observations of open-grown trees and we have observations of suppressed trees. All that is required is to provide a model of potential growth rate for open-grown trees and then apply a modifier function for relative position in the stand and a modifier function for stand density as in figure 6. Growth models of this type are available. Yields are most often projected from stand models through extrapolation; interpolation is most often used to project yield from a tree-list model.

Tree-list models are biologically simplistic and provide us the opportunity to draw more information from existing permanent plot studies than analyses for stand average models. For this reason I disagree with the statement made earlier in this conference that "modelers are more plentiful than good data." There are a significant number of silvicultural and growth trend studies for our major commercial species throughout the West, and we have not fully used these studies in modeling for growth and yield. Installing new studies should come second to a more vigorous attempt at using existing data.

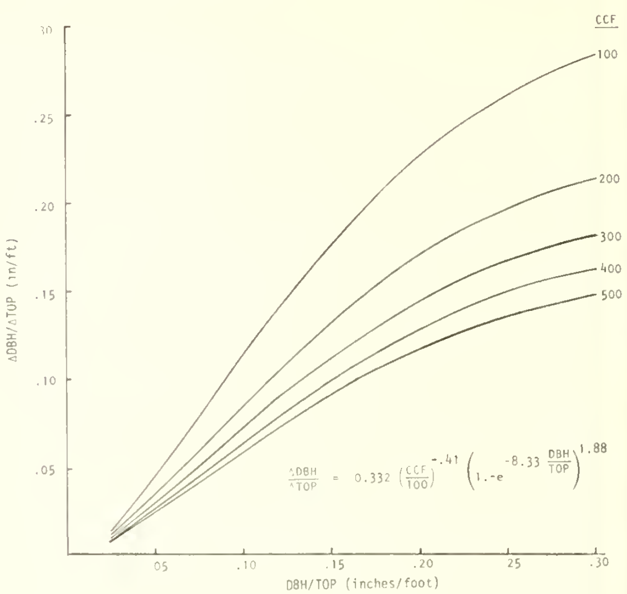

Figure 6.--Relationship between predicted growth and relative size and density.

About the availability of modelers! A good model, as stated earlier by Curtis and Hyink, requires good biological as well as mensurational knowledge. In my view, this comes from a team of mensurationists, silviculturists, soil specialists, and others. In the last 10 years, for a variety of reasons, we have moved away from these kinds of team reseach programs. Other professions are expanding their use of interdisciplinary teams successfully. Avenues open to us are group contract, cooperative research programs, or both. No really good prototype exists for us to follow. Existing cooperatives have been too weak on analytical studies and too heavy on measuring more trees. The new Inland Northwest Growth and Yield Cooperative (1984) has the potential to develop a strong analytical approach to growth modeling. It is being used as a prototype for similar cooperatives in the Canadian Provinces. If these cooperative research programs are successful, we should see a marked improvement in the flow of mensurational technology over the next few years.

RECOMMENDATIONS

I would like to close with the following recommendations:

1. Do not mix inventory plots with growth plots.
2. Inventory includes volume, vigor, and defect by species and diameter class.
3. Record site index for all species on a 50-year d.b.h. age basis.
4. Stratify your ownership using soil-site and growth-type relationships.

5. Apply taper equations in all volume calculations.

6. Record change on growth plots as survivor growth, ingrowth, and mortality.

7. Consider tree growth models as the preferred stand projection approach.

8. Take advantage of contract research and cooperative programs to supplement in-house programs.

9. Utilize existing data to the fullest extent before establishing new installations.

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COLLECTING GROWTH AND YIELD DATA: A CONTRACTOR'S OPINION

Gordon L. Younker

ABSTRACT: AAA Engineering and Drafting, Inc., presents three points regarding mapping and data collection contracting: (1) Invitation for Bid procurement often compromises data quality by ignoring other critical contractor characteristics. (2) Many government agencies do not recognize the advantages of outside contracts, which often produce increased quality at lower cost. (3) Outside contractors can sometimes share relevant experience and thus eliminate the need for a government agency to repeat steps that have already been taken by others.

INTRODUCTION

AAA Engineering and Drafting, Inc. (AAA) offers the perspective of a contractor who has gathered forest data according to detailed contract specifications designed by government foresters and contracting officers. In the last 10 years, AAA has been awarded and has completed 59 forestry inventories and mapping projects on 42 Forests throughout the United States. Projects have included timber and vegetative delineation and classification of aerial photography, forest mapping, and continuous forest inventories. Forestry inventories have included the establishment of permanent plots and the remeasurement of plots established in earlier inventories. Presently, AAA is remeasuring pinyon-juniper fifth-acre plots, including woodland volume estimates using the visual segmentation technique.

During the last 5 years, AAA's employment has grown from 80 to 150 professionals and technicians. AAA's major emphasis continues to be mapping, with 70 percent of the corporation's current business with the Defense Mapping Agency.

THREE CONCERNS

The following three points are concerns of AAA as relates to the contracting for mapping and data collection.

1. AAA believes that the quality of data, which is the basis for effective growth and yield models and which has been referred to numerous times here, is too often compromised by the Invitation for Bid (IFB) procurement or "lowest offer gets the project" contracting. Though competition and costs are of tremendous importanc neither should be sought at the expense of good data. The often-used adage "you get what you pay for" should be considered when contracting for these services. The Request for Proposals (RFP) procurement encourages competition and enables selection of a qualified contractor. Though prices are moderately higher than under a low-bidding procurement, they are reasonable for the services required. Under the low-bid system, the government sometimes spends more money inspecting the contractor's work than the contractor is pai for the services. Although RFP procurement enables the government to consider both a contrac tor's qualifications and offered price, when exa and proven specifications become available contracts are often awarded solely on the basis low bidding. In these situations specifications should include strict qualification standards an performance bonds. Overall, large projects will yield better data if contracted to one contracto than if split among many different contractors.

2. In these times of reduced budgets, some agencies still resist contracting for forest dat gathering services, believing that only menial tasks should be contracted outside the governmen and university environments. Apparently, the basis for this practice is the belief that outsiders, including the small business community, cannot be trusted or will reduce the government employee's job security and responsibility. In fact, aggressive Regions and Forests have succes fully contracted for years; the results have be increased quality and significantly lower costs than traditional government programs. AAA belie even greater opportunity exists to maximize the services needed to manage resources within the dollars available, if contract services are procured and procured properly. Many more servi could and should be contracted.

Good contract specifications allow the governmen to maintain tighter quality control than is possible with force account or in-house crews. The total cost to the government of contracting project is approximately one half the cost of th same work when completed by government force account crews. This total cost comparison considers both the contract price and cost of the government to administer the contract. The much reduced cost of contracting should in itself result in serious consideration for procuring a contractor's services.

Paper presented at: Growth and Yield and Other Mensurational Tricks: A Regional Technical Conference, Logan, UT, November 6-7, 1984.

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3. There are a few writing contracts who think their project is the first of its kind. They seem to begin their contracting programs from scratch, learning the right ways only after bad experiences. Often, as close as the Forest or Region next door, similar contract experience and programs exist. AAA was impressed by the Rome-headquartered FAO forester who requested AAA copies of past Forest Service and BIA contract specifications for forest mapping and inventory to help design a contract program to complete similar work in the Caribbean.

A CHANCE TO SHARE

AAA Engineering and Drafting, Inc. (AAA) welcomes the opportunity to share its contracting experience with those here at home in the United States as well. AAA has become acquainted with many in attendance at this conference through its contracts with a variety of Government agencies. We are glad for these opportunities to provide service within the profession and appreciate the professionalism we have found.

GROWTH AND YIELD MODELING: WHERE DO WE GO FROM HERE?

Alan G. McQuillan

ABSTRACT: This paper focuses on the need to establish permanent plots but identifies the numerous problems associated with them, ranging from which variables to measure, designing and stratifying the sampling system, obtaining adequate funding, data collection problems, resistance to change in approaches, and statistical reliability to discontinuity in personnel, policy, and funding. Proposed solutions include support from top personnel and organizational policy to prohibit external interferences in and around permanent plots and a cooperative administrative effort to ensure continuity of personnel, policy, and funding. Miscellaneous responses to issues raised at the conference are also included.

INTRODUCTION

I would like to respond to some of the papers we have heard in the last 2 days . I liked John Teply's remarks on the need for reconciliation between successive inventories. In academic environments we are usually concerned with continually trying to find new and better ways to design the wheel, but from my industry experience I know that when we come out with a new timber inventory there are always questions asking us to explain the differences between the new and the old inventories. When sampling procedures, volume equations, and other methodologies have been changed, this is not always easy.

I liked all of Ralph Johnson's remarks on the problems of calibrating models for new areas, gaining user acceptance, finding out what is really going on in a new area, and especially the importance of quality software maintenance. This last item is all too often ignored. I have worked on Forest Service contracts to provide software, usually economic software, and I always had the feeling that once these models were delivered they would not ever be used, because as soon as the recipient begins to work with a new piece of software, he starts to find changes that he would like to make. Often when relatively small models are provided under contract, the project is completed, the program is wrapped and tied with a ribbon and delivered, and that is the end of the contractual obligations. There are no provisions, and it would be very difficult to make provisions in some cases, for the modeler to come back periodically and change the program as needed. Hence, these things end up on a shelf gathering dust. I read in one of the computer journals that nationwide about 50 percent of all software costs are for maintenance, which illustrates just how important software maintenance is

I liked Bill Wykoff's definition of that illusory thing that we call a timber stand. If I remember correctly, Bill referred to a stand as a unit of land that is comprehensible to other specialists. This is probably about as close as we can hope to come to a precise definition.

I learned from Charles Chambers why Beers' method of using variable plots for growth measurement is unbiased. I always had the feeling that it was all right to ignore ongrowth trees, but now I know the exact rationale for doing this. And I learned from Roger Chapman about the bias that enters when current tree diameters are used with variable plots to estimate growth. This is a mistake that I have made in the past, and I did not realize it until yesterday.

SEPARATE MODELS?

This morning I was spurred once more to thinking about the problems of volume estimation, and the more I think about it the more I become convinced that we should explicitly separate growth models from volume estimation routines. That is, when doing growth modeling we should concentrate on making projections in terms of tree characteristics.

Specifically, we need to produce tree lists or stand tables showing number of trees by species and d.b.h. classes. Then we should endeavor to superimpose height information in the form of mean height for each d.b.h. class or, preferably, in the form of a height distribution within each d.b.h. class. If this gets too complicated, a tree list would suffice.

With a detailed stand table or tree list in hand, we can then worry about the entirely separate problem of volume computation. Ecologists, energy specialists, and other people interested in fiber yields can worry about generating cubic volume or biomass weight from a tree list or stand table; salespeople can worry about cruise volume or Scribner scale in terms of 16½-ft logs. For industry people, scale using a standard log length is usually not meaningful, but they can take stand table or tree list information and apply taper equations to feed utilization and bucking simulation models to estimate actual product recovery from the inventory or stand growth projections.

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PERMANENT PLOTS

Finally, I heard a lot of talk yesterday about permanent plots. It seems that everybody is renewing their interest in permanent plot installations for growth model validation or improvement. Some growth data can be obtained from destructive sampling such as height growth and d.b.h. increment, but some things can only be reliably tracked using permanent plots. This is especially true of mortality data. It is also true for crown ratios. It might be possible to reconstruct past crown ratios using stem analysis data, but it would be very difficult . Yesterday there seemed to be unanimous concurrence on the need for a system of permanent growth plots, and I would agree.

I am somewhat disturbed, however, at the prospect of people rushing out to install their own systems of permanent plots, although that may be inevitable. Every organization has its own specific needs with respect to growth information, its own ideas, and its own constraints on the nature of permanent plot installations. The lack of permanent plot data in the northern Rockies today is not entirely due to a lack of plot establishment in the past. From evidence I have encountered, I have gained the impression that many so-called permanent plots have been established in this region in the last 50 years; however, there has been much attrition in the permanent plot data base. This follows naturally for many reasons and can undermine the usefulness of permanent plots for long-term growth monitoring.

What are the problems with permanent plots? There are many.

1. There is the problem of which variables to measure, and fashion regarding this changes. For example, although crown ratio is a popular proxy measure for tree vigor today, I inherited a set of permanent plots on which crown ratio had not been measured because at the time the plots were designed nobody thought crown ratio was important. So now we go out and superimpose crown ratio measurements on these plots. By tomorrow, or 5 or 10 years from now, we will undoubtedly have discovered new tricks and new variables which we feel give us a better handle on growth prediction. At present, there is frequent discussion of measuring sapwood basal area. Should we measure it or not? The only safe course is probably to measure everything that we can think of and to map the trees as well, but it becomes difficult to justify the expense to managers when we are not sure what is needed. Even if we do measure everything we can think of, we will still not have enough data because future researchers will undoubtedly think of new things.

2. There is a problem keeping harvesting out of permanent plots. This might sound like a simple problem, but it is not always easy to solve.

3. There is a problem finding permanent plots for subsequent remeasurement. I have been involved in quite a few projects where a large number of plots measured previously could not be located for remeasurement in a cost-effective manner.

4. There is a problem designing the sampling system and the stratification used for laying out the plots. Whatever system we decide upon, we will no doubt find in retrospect that it compromises what we later try to do with the plot information.

5. There is the obvious problem of inadequate and discontinuous funding (which I shall return to later). Adequate initial funding is necessary, as is continued funding, because although some permanent plot data are useful immediately, the real gains accrue only over several decades.

6. There is a problem obtaining quality data. Data used for growth research must be of a higher quality than that used for point-in-time inventories. This problem is not peculiar to permanent plots, but when we measure plots, there can be inconsistency between the quality of data obtained in one time period and the next. We heard references yesterday to the problem of obtaining accurate height measurement.

7. There are some peculiar problems related to the technology of record keeping. In the 5 or 10 years between measurements, significant changes have usually been made to the computer systems; this makes necessary reformatting or some other data manipulation.

8. There is the problem of deciding which trees to measure. What minimum d.b.h. will we use? Will we measure small trees on a smaller plot and large trees on a larger plot? Will all trees, especially small trees, be numbered? We usually cannot afford to measure all small trees on the same plot size used for large trees and cannot afford to individually tag and number all small trees. Yet if we do not, the problems of accounting for ingrowth and ongrowth and differentiating these from simple coding or measurement errors can be substantial.

9. The value of a permanent data base will decrease if there is not substantial and continued resistance to changing the plot measurement system. From one measurement to the next there is often pressure to drop certain variables which have gone out of fashion and to save time by so doing. Because we never really know which variables are going to stay out of fashion and which ones might come back, it is dangerous to drop variables simply because current thinking suggests they are no longer useful. In addition, entire plots are dropped if they no longer seem to be of interest. The concept of what we mean by managed stands can change radically from one decade to the next. As economic conditions worsen, interest in natural regeneration with little or no site preparation

can rebound, and we might regret decisions which assume that intensive forestry is the name of the future game. There are also obvious problems with changing measurement procedures and skipping measurements. Another important problem is the tendency of researchers to squeeze as much information out of the system as possible and thus to superimpose new treatments on an existing permanent plot data base. For example, they may suggest that half the plots should be fertilized or the trees pruned. It does not require many new levels of treatment on a data base to destroy the integrity of the entire system.

10. There is a problem achieving statistical reliability when growth estimates are calculated as the difference between two point-in-time inventories, each with its own error characteristics. If we measure height plus or minus 2 ft the first time and again plus or minus 2 ft the second time, and if these measurements are 5 years apart, we may generate the kind of problem I'm talking about. Say the tree actually grew 5 ft in 5 years and the first measurement was 2 ft high and the second measurement was 2 ft low: we would conclude that the tree had only grown 1 ft over the 5-year period--a substantial error. I have looked at more than a few permanent plots where trees apparently shrunk over time.

11. A major problem relates to discontinuity for personnel, motivation, interest, and funding. Maintaining permanent plots is not a job to be foisted upon reluctant personnel unless they are to be adequately recompensed and recognized for their efforts in this regard. I shall return to this later.

None of these problems indicate that we should not install permanent plots. We need to. But if we are to spend a lot of money on them, we should seriously consider ways to overcome the problems I have described; otherwise our money is probably wasted.

Standards Needed

Regarding variables, plot size, sample design, and so on, we should get together on some agreed upon standards. Then data from different organizations would be compatible, and the whole would amount to more than the sum of the parts. Bob Curtis was probably right when he said the plots should be large.

Establishing permanent plots requires motivation and support from people high up in the organization because their endorsement is critical if we are to prohibit harvesting in and around plots and other external interferences. We need administrative weight behind these prohibitions, and even this will not be enough because top personnel and organizational policy change over time. Unfortunately, there isn't any way to prevent this. Ideally we need to be protected by a set of procedures that is akin to the U.S. Constitution. Changes or discontinuities in the permanent plot system would thus be difficult to accomplish without the concurrence of almost all interested parties.

I do not know how to do this administratively. A cooperative, such as the recently formed Inland Northwest Growth and Yield Cooperative, could help achieve continuity and control, but only if we could ensure the cooperative's longevity, which is not an easy task.

We also need secure funding, which is probably the most difficult of all to achieve, as I'm sure everyone here realizes. Ideally we would establish a trust fund, the interest from which would be used to fund remeasurement and data base maintenance. This would prevent long-term permanent plot study disruptions caused by short-term budget crunches and other crises. In addition, we should employ someone whose career success depends on the success of the permanent plot system.

Continuity Is Central

These ideas might sound expensive and unrealistic. Cooperative administration might make them less so if expenses and personnel were shared. The continuity of this arrangement would, of course, be central.

If these proposals sound too much like pie in the sky, we must ask ourselves how badly we really want permanent plots. There is not much point establishing a myriad of plots in the vague hope that some of them will survive to be remeasured for the next 50 years. If we really need the permanent plots, we should seriously seek ways to ensure their longevity and increasing usefulness. If we are trying to fund the project on a shoestring, it probably will not survive and we are probably wasting whatever little money and considerable effort we are spending on establishing the plots in the first place. This has happened in the past, and there is nothing to prevent its happening again.

I would like to see future discussion of the permanent plot question focus on ways that might ensure, or at least increase, the chances for such a program to succeed.

GROWTH, YIELD, AND MENSURATION:

A FEDERAL USER'S PERSPECTIVE

Milo J. Larson

ABSTRACT: Users are faced with an array of techniques to help them quantify timber information and to use it for projections. The amount of choice has advantages but at the same time impedes the flow and understanding of information.

INTRODUCTION

Within any level of an organization, there are almost as many perspectives as there are individuals responsible for the work. Each mensurationist has his or her own perspective. All of these perspectives are difficult to judge objectively and are often not well articulated. In many cases, resource managers must generalize about highly variable situations without benefit of any measurements whatsoever. The information presented here consists of just such generalizations about problems in the mensuration of growth and yield.

GROWTH AND YIELD

Yields are now projected almost exclusively by models. Growth is measured, but often is not used for much unless it is required as an input for a model. Some of the models in use in the Rocky Mountains are discussed in the following sections.

RMYLD And Its Variations

This model is a whole stand model that has proved useful for making silvicultural comparisons for even-aged stands. It is simple, easy, and inexpensive to run, and hundreds of alternatives can quickly be generated by it. Although it is used in Forest Planning, it has several drawbacks: built-in assumptions for a relatively high intensity of management; inability to closely match inventoried volumes at the starting point for projection; much wider variation within a summarized inventory strata than in stands selected as a basis for the model; and the inability to project variations in species composition or diameter distribution.

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R-2 GROW

R-2 GROW is a diameter class model derived from Region 2 inventory data. The model is simple to run. It can simulate even-aged management and roughly simulate uneven-aged management. It has proven to be a good model for projecting existing inventory summaries. It can be used for projecting silvicultural alternatives in individual stand prescriptions, but it is not designed for individual stands and its data for seedlings and saplings are poor.

Stand Prognosis Model

This individual tree model has been discussed fairly extensively at this workshop. I have little to add except that it has been a good model for stand projection and for planning projections. Its drawbacks are that it is data demanding, and elaborate calculations are needed to make the projections.

PIPO

PIPO is a model that has been useful in Regions 2 and 3 to make stand projections for even-aged ponderosa pine. It has not been used in land management planning. It has some of the drawbacks inherent in RMYLD and, in addition, the only versions I have used are interactive with the computer, which is a great inconvenience if many projections and stands are involved.

ECOSIM

This model is an individual tree model patterned after the STEMS model. Region 3 planning teams like this model because it is possible to generate joint production functions for use in planning. It has been little used for individual stand projections. There has been some argument over the veracity of the projections, but our experience indicates that reasonable projections are obtained. It also requires some fairly complex calculations and has been known to bring the Fort Collins Computer to its knees when large numbers of runs are needed.

Models In General

The assortment of models and additional models in the works, such as the GEM model proposed by the

Rocky Mountain Station, offer advantages to the manager but also present a dilemma because none seems entirely applicable in a given situation. Each requires different data as input. Most disconcerting to the user is the number of advocates and detractors within the mensuration community for each model.

VOLUME AND BIOMASS DETERMINATION

Presentations here have focused on various techniques for different classes of trees and species. From the user's point of view it is essential to base estimates on parameters that are easily, routinely, and consistently measurable. The variables are, after all, abstractions of reality. When mensurationists emphasize variables too much, the result is to make plot taking exceedingly costly and prone to error.

Timber mensurationists treat forked trees differently than woodland mensurationists. The mensurationist finds he or she can improve the fit by using a height to live limb ratio on one species but not on another, and so on. From the user's point of view, if it is made out of wood and can eventually get to a certain size, it's a tree. We are not happy with tally sheets a yard long and instruction packages 2 inches thick. We are not interested in having a research plot at each sample point. We have too many situations to sample and tend to cope with rather large sampling errors. Words like consistent, simple, fast, and inexpensive loom large in an era of budget cuts.

Another area of concern is volume equations. Volume equations have been developed over and over again for the same species. Countless trees have been felled or otherwise segmented, yet we seldom have the equation we want or need. If we had the base data itself and a somewhat consistent methodology for doing the field measurements, the equations could be upgraded with far less cost and much better results. It may be a lot to ask, but we should develop such a procedure and follow it.

BALANCING MEASUREMENT PRECISION AGAINST THE GUESSES

As a user, it seems that we sometimes go overboard on precise measurements of what we can measure and then add, subtract, multiply or divide by factors that can only be derived by guess work. It is probably one of the bigger weaknesses in users.

How closely should you project growth when you have to guess at mortality? How closely do you have to measure trees on cruise plots when the observed defect is mostly guesswork, the unobserved defect is totally guesswork, and breakage is a decree by the Supervisor's Office? I don't know the answers to these questions, but I can't escape the feeling that we often measure much too closely for the estimate required. Are both users and mensurationists prone to the trap of "Because it is possible, it must be necessary"?

ADMINISTRATIVE BARRIERS

One of the major road blocks to progress in the areas we are talking about is the tendency of each administrative jurisdiction to develop its own bag of tricks. Each school, each agency, each unit within an agency tends to go its own way for measurements and growth estimations if personnel have the skills to do it. Individually, the methods may be good. Collectively, they create confusion and retard the flow of information. When you look at a given process, such as cruising or stand examination, you find striking similarities and many procedures are <u>almost</u> identical. In a computer age, however, the situation poses a problem. To a computer, "almost identical" and "totally dissimilar" are equally unusable.

There are encouraging signs, such as the spread of the Stand Prognosis Model and recent efforts to coordinate examination and inventory procedures between Regions 2 and 3 of the Forest Service. Although the advantages of standardization need to be weighed against the advantages of custom-designed approaches, I see increased standardization as a way to get better answers with less work in many situations.

TECHNOLOGICAL ADVANCES

Electronic data recording and decentralized data processing are rapidly approaching and should greatly enhance the ability of field units to handle mensurational work. Nevertheless, most field units still do not have the hardware they need, and most higher headquarters have not completed software or instructions needed to make it go. It also seems likely that we are vulnerable to a lot of wheel spinning as these devices are acquired. The "no two alike" situation seems unavoidable until the shakedown period passes. Hopefully, we can minimize the time, expense, and frustration of this interim period.

SUMMARY

Many mensurational tools and techniques are available for users in meeting their information needs. The array enables use of tools to meet many specific needs and situations. At the same time inconsistency and lack of standardization make comparisons of measured data very difficult. Effort by the mensurationists to maintain or improve standardization of both measurements taken and the summarized data will be greatly appreciated.

NATURAL RESOURCE ASSESSMENT FROM A STATE PERSPECTIVE

T. Michael Hart

ABSTRACT: Managers of public lands, especially those administered by State agencies, must be able to justify the expenditure of program funds. Often the questions asked of these managers are not easy to answer based on resource values alone. Thus, the methods used to develop viable resource plans must be quantitative rather than speculative and must be able to accommodate modification to meet local needs.

INTRODUCTION

All of us, as land managers, are being asked by the users of the land we manage and by our funding sources to describe the total resource that has been placed in our care, and explain the logic of our management decisions. Our ability to determine present and predict future supplies of natural products, and to predict future consequences of present land management decisions, depends upon measurements and models predicting volume, biomass, growth, and yield.

THREE KEY QUESTIONS

Describing natural resources to answer the question, "Where do the resources occur and what do they look like?" usually involves preparing maps and statistics. Vegetation must be described by species, size distribution, numbers, acres occupied, and by the ecological relationship of plant and animal communities to each other. Normal successional patterns are also an important factor in describing our resources.

The next question often asked, "What are the resources good for?" often requires converting the "where and what" assessment into products and dollars. This includes values relating to recreation, wildlife, grazing, forage, and fiber production. The values are constantly fluctuating, as is the "use" of the resources themselves.

An excellent example of this in Arizona is the sudden, rather unexpected, demand for fuelwood from the pinyon-juniper and mesquite areas of the State. A market suddenly existed for tree species that had in the past been considered a detriment to other wildland uses and values.

The last question asked by our users and funding sources that we must address is, "What resource changes are taking place, both natural and human-caused, and what are the consequences of the changes?" Changes considered include normal growth, and mortality resulting from fire, insects and disease, and windthrow. Human-caused changes such as logging, thinning, planting, results of prescribed fire, and urbanization must also be evaluated.

PLANNING NEEDS

Most of the State forestry organizations of the Nation are presently in the process of developing State Forest Resource Plans. The Plans must consider forest production from all ownerships and how they relate to the economic development of the State. The key to a viable resource plan is to have an accurate State-wide assessment of current supply of all forest resources, not traditional wood products only. Resource plans also must predict demand, examine management alternatives, analyze benefits, and establish a recommended program for all ownerships to help meet State goals. The State's ability to prepare State Forest Resource Plans depends upon viable mensurational systems to measure growth and yield, and predict future changes in the resources managed. "Educated guess" speculation on growth patterns and successional changes in plant communities resulting from land treatment and management decisions is often not accepted by the public and users of the land. Demand for conflicting and competing goods and services from the land will only increase in the future. Our need to "prove" that the dollars we spend in protection and management are justified by the returns expected will, most likely, intensify before future funding will be provided.

Many of the measurement and modeling systems developed during the last 10 years do an excellent job of providing specific information for a specific situation. A more general approach, with room for local modification for specific needs, could be more useful. All modeling and measurement systems should be usable and of benefit to the manager on the ground who makes and defends management decisions. The systems should be of use in establishing funding for treatment priorities, program priorities, and allocations of personnel. The measurement and

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modeling systems should be easy to modify or change as more knowledge becomes available, or different types of information are needed.

Finally, measurement and modeling systems should consider (to the extent possible) all forest species and stand conditions, and not be limited to a particular product or present definition of "commercial" forest type. Our ability to respond to quickly changing demands for products from the land will depend on how well we have assessed our resources. The risk in management decisions can be minimized only with reliable resource information.

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Contains 22 papers exploring current advances in measuring and computing growth, examining modeling systems for determining yield, and discussing new and traditional methods for determining volume of woody species.

KEYWORDS: volume, modeling, biomass, sampling

The Intermountain Research Station, headquartered in Ogden, Utah, is one of eight Forest Service Research stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station's primary area includes Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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BEHAVE: Fire Behavior Prediction and Fuel Modeling System—

BURN Subsystem, Part 1

Patricia L. Andrews

PREFACE

The BURN subsystem of the BEHAVE system is made up of state-of-the-art fire behavior prediction models. These models are the culmination of many years of research, not only from the Intermountain Fire Sciences Laboratory, but from fire research throughout the world. As additional mathematical models become available, they will be added. In this way, we plan to use BEHAVE as a means of getting research products into application. Therefore, BEHAVE **will** change. In most cases, this means additions to the system. However, it is possible that revisions will be made to existing models. The version number of the program will be used to keep track of the changes. Version 2.1 was used in preparing this manual. The version number of the program is printed at the beginning of each run along with the welcome. Future versions of programs in the BURN subsystem will print the version number with the predictions.

At the time of this writing we are working on an update to the system, BURN Subsystem - Part 2. A manual similar to this will be prepared.

THE AUTHOR

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RESEARCH SUMMARY

The BEHAVE fire behavior prediction and fuel modeling system is a set of interactive computer programs. The BEHAVE system is made up of two subsystems: the fire-behavior prediction subsystem, BURN, and the fuel modeling subsystem, FUEL. The FUEL subsystem of BEHAVE is described in a separate publication (Burgan and Rothermel 1984). This manual describes the BURN Subsystem, Part 1. (Other parts of BURN will be added as research is completed.)

This manual covers operation of the computer program, including a detailed example run in the appendix. Assumptions and limitations of the mathematical models that drive the predictions are discussed. Appropriate application of the predictions is emphasized.

Fire behavior predictions that can be obtained include rate of spread, flame length, intensity, area, perimeter, attack force requirements, and spotting distance. Potential applications of BEHAVE are dispatch of initial attack forces, wildfire growth predictions, prescribed fire planning, and training. The National Fire-Danger Rating System (NFDRS) and BEHAVE are compared.

CONTENTS

BEHAVE: Fire Behavior Prediction and Fuel Modeling System—
BURN Subsystem, Part 1

Patricia L. Andrews

INTRODUCTION

The BEHAVE fire behavior prediction and fuel modeling system is a set of interactive, "user-friendly" computer programs. It is a flexible system that can be adapted to a variety of specific wildland fire management needs. BEHAVE is ideally suited to real-time predictions of the behavior of wildfires or unplanned ignition prescribed fires. It can be used in fire behavior training and initial attack dispatch of fire crews. With proper care, it can be used in prescribed fire planning. BEHAVE is of limited use for predicting fire effects and it will not satisfy the broad area planning needs met by the National Fire-Danger Rating System.

BEHAVE draws together state-of-the-art fire behavior prediction technology into one easy-to-use package. Many of the mathematical prediction models in BEHAVE have been available for application in other forms. For example, the TI-59 handheld calculator with a fire behavior CROM (Custom Read Only Memory) (Burgan 1979a) has been widely used as a method of calculating fire behavior in the field. BEHAVE does the calculations that the TI-59 does, and more. BEHAVE will likely replace the TI-59 for office work, although there will be a continued need for a portable field tool. Other methods of obtaining the fire behavior predictions that are in BEHAVE include, for example, the tables in the S-390 Intermediate Fire Behavior Course (National Wildfire Coordinating Group 1981), nomograms (Albini 1976a; Rothermel 1983), calculator programs (Albini and Chase 1980; Chase 1981), and computer programs (Albini 1976b). BEHAVE also offers options that are not available elsewhere, the most significant being that of allowing the user to design custom fuel models. Use of BEHAVE for fuel modeling is described by Burgan and Rothermel (1984). This paper covers use of BEHAVE for operational fire behavior prediction.

The author of this handbook assumes that the reader has had experience with fire behavior prediction. The major prediction techniques are covered in Richard C. Rothermel's (1983) "How to Predict the Spread and Intensity of Forest and Range Fires." The material in that publication is based on the Interagency S-590, Fire Behavior Officer Course, and is directed toward field use. The same basic procedures, however, are used for other applications.

The bulk of this handbook describes the basis of the predictions and specific application of BEHAVE. A relatively small section describes operation of the computer program. "User-friendly" design eliminates the need for detailed instruction.

BEHAVE SYSTEM DESIGN

SYSTEM — SUBSYSTEMS — PROGRAMS — MODULES

- BEHAVE
  fire behavior prediction and fuel modeling system
  - FUEL
    fuel modeling subsystem
    - NEWMDL
      initial fuel model development program
    - TSTMDL
      fuel model test and adjustment program
  - BURN
    fire prediction subsystem
    - FIRE1
      prediction program
      - SITE
        spread rate and intensity calculation module (site - specific input)
      - DIRECT
        spread rate and intensity calculation module (direct entry of general input)
      - SIZE
        area and perimeter calculation module
      - CONTAIN
        attack force requirement calculation module
      - SPOT
        maximum spotting distance calculation module
      - DISPATCH
        automatic linking of DIRECT , SIZE, and CONTAIN
    - FIRE2
      prediction program
      - Calculation modules to be added later

Figure 1.—Subsystems, programs, and modules of the BEHAVE system.

THE BEHAVE SYSTEM

The BEHAVE system (fig. 1) is made up of two subsystems: the fuel modeling subsystem, FUEL, and the fire behavior prediction subsystem, BURN. The FUEL subsystem of BEHAVE is described in a separate publication (Burgan and Rothermel 1984). This manual describes the BURN subsystem: operation of the computer program, the mathematical models that drive the predictions, and application of the predictions.

FUEL offers a systematic method of building fuel models to cover specific situations. The FUEL subsystem of BEHAVE consists of two programs—NEWMDL ("new model") and TSTMDL ("test model"). NEWMDL is used to initially set the values for the fuel model parameters; then TSTMDL is used to examine the fire behavior predictions using the fuel model and a variety of environmental conditions. The values of the fuel model parameters can be adjusted if necessary.

The BURN subsystem of BEHAVE is used for predicting fire behavior. BURN currently consists of one program, FIRE1. Another program, FIRE2, will be added to the BEHAVE system at a later date. The program is divided into modules (fig. 1). The major modules of the FIRE1 program are SITE, DIRECT, SIZE, CONTAIN, and SPOT. SITE and DIRECT are for predicting spread rate and intensity. SIZE calculates the area and perimeter of a fire that started from a point source and has a roughly elliptical shape. CONTAIN calculates the final fire size based upon user-specified control force capabilities, initial fire size, and environmental conditions. Conversely, CONTAIN can also

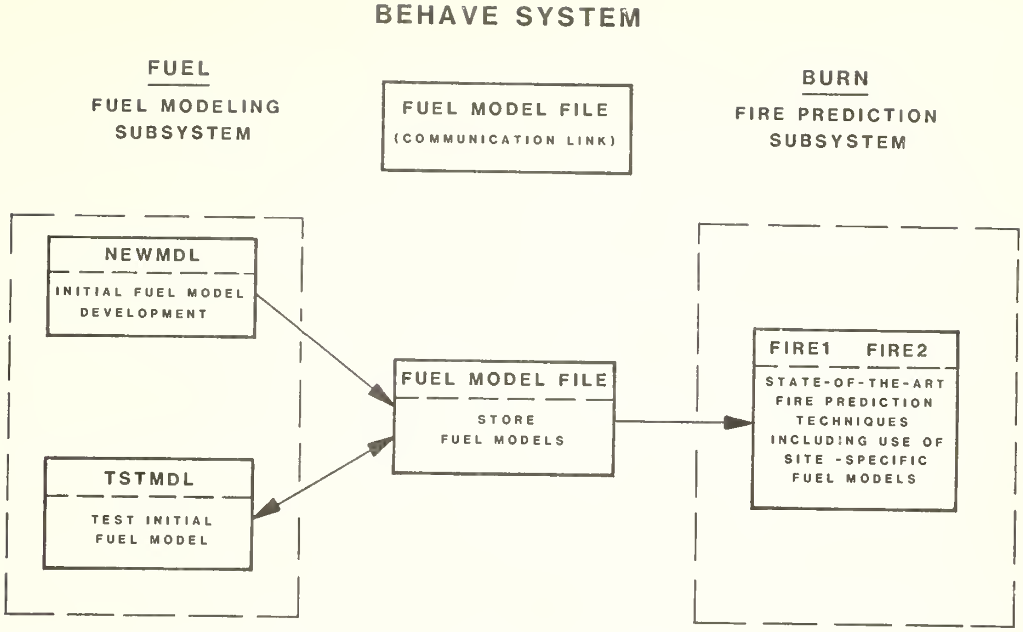

Figure 2.—The fuel model file is the communication link between the two BEHAVE subsystems, FUEL and BURN.

estimate the control forces required to contain the fire at a specified size. SPOT gives the maximum spotting distance from a torching tree or a burning pile of debris. The modules can be run independently or they can be linked, with the output from one being carried as input to the next. As new fire behavior prediction models become available, they will be added to the BEHAVE system.

The link between the FUEL and BURN subsystems consists of files of the custom fuel models that users design and save through FUEL (fig. 2). These fuel models can then be used by BURN through access to the files. Once the file name is specified, fuel models are referenced by number, as are the standard 13 NFFL fuel models. Appendix C is devoted to the subject of fuel model files. Understanding the fuel model file concept is basic to proper use of the BEHAVE system.

BURN and FUEL are separated as subsystems because of their mode of use. BURN can be used totally independent of FUEL if only the 13 standard NFFL fuel models (Anderson 1982) are used. FUEL is used to expand the basic set of 13 NFFL fuel models. Site-specific fuel models are developed for a given area of concern, a National Forest for example. This may be done by the fuel specialist on the Forest. BURN will be run in an operational mode, possibly utilizing the fuel models developed earlier. A wider range of people will use BURN. A dispatcher, for example, would not be likely to build fuel models. Therefore, it is not necessary to learn to use FUEL before reading this publication and learning to use the BURN subsystem of BEHAVE.

OPERATING INSTRUCTIONS

FIRE1 is a "user-friendly" program. It asks you questions. If you respond incorrectly, it will tell you so then ask the question again. You should not be able to "crash" the program. Some of the questions require a yes or no response, some ask for an input value, and others request keywords.

An example of a user's session with FIRE1 is given in appendix A. If you are just learning about BEHAVE, I recommend that you read appendix A now

so you can see how the system works. Examples of everything described in this section on operating instructions are included in the appendix. Hands-on practice, however, is the best way to learn to run the FIRE1 program.

Keywords

The keywords give FIRE1 its flexibility. A list of the keywords and a brief description of each is given in exhibit 1.

Mode keywords	
WORDY	prints extra messages and explanations throughout the run (default)
TERSE	skips extra messages and explanations
PAUSE	limits output to at most 24 lines at a time for a terminal with screen display
NOPAUSE	prints output without pause for a terminal with hard copy output
Rescue keywords	
KEY	prints the keywords that are allowed at the current point, along with a brief description of each
HELP	tells you where you are in the program and what you can do next
Module keywords	
DIRECT	accepts direct input of the basic input values to calculate spread rate and intensity
SITE	accepts site-specific input to calculate spread rate and intensity
SIZE	calculates area, perimeter, length-to-width ratio, and forward spread distance
CONTAIN	calculates line construction capabilities needed or final fire size
SPOT	calculates maximum spotting distance
DISPATCH	automatically links DIRECT, SIZE, and CONTAIN
Operation keywords	
INPUT	asks for all input of the current module
LIST	lists current input values
CHANGE	changes individual input values by line number
RUN	does calculations and prints results
Other Keywords	
QUIT	gets back to the previous level in the keyword hierarchy or terminates the run
CUSTOM	specifies a custom fuel model file to be used or lists what is in a file

Exhibit 1.—FIRE1 keyword summary.

The "mode" keywords are WORDY, TERSE, PAUSE, and NOPAUSE. They are used to set a mode to be applied until you change it. These keywords can be entered any time a keyword is requested.

WORDY - Prints additional explanation and messages throughout the run. You will definitely want to use the WORDY mode while you are learning to use the program. And there is nothing wrong with always using the WORDY mode. The default mode is WORDY.

TERSE - Cancels the WORDY mode. You may want to use the TERSE mode when you become so proficient that you can anticipate what will be printed next. This mode is especially useful when you are using a hard-copy terminal and want to speed things up.

PAUSE - Causes output to be limited to at most 24 lines at a time. There is no reason to use this mode when you are using a hard-copy terminal. When a prompt symbol is printed without a question, the program is pausing until you indicate that you are through viewing the output. Press the return key to indicate that you are ready to continue. The PAUSE mode is also set when you answer "YES" to the question at the beginning of a run: "ARE YOU USING A TERMINAL WITH A SCREEN ? Y-N".

NOPAUSE - Cancels the PAUSE mode. The NOPAUSE mode can also be set at the beginning of a run by answering "NO" to the question "ARE YOU USING A TERMINAL WITH A SCREEN ? Y-N".

The "rescue" keywords are HELP and KEY. They can be entered any time a keyword is requested. The response should rescue you if you get mixed up.

KEY - Lists the keywords that can be entered at this point. A brief description is given for each.

HELP - Tells you where you are in the program and what you can do next.

The "module" keywords are DIRECT, SITE, SIZE, CONTAIN, SPOT, and DISPATCH. They are used to get you into a specific fire behavior prediction module. Appendix B includes input/output forms for each module and descriptions of input variables.

DIRECT - Calculates rate of spread, flame length, fireline intensity, heat per unit area, reaction intensity, effective windspeed, and in some cases direction of maximum spread. You can calculate fire spread in the direction of maximum spread when the wind is blowing cross-slope, or in any other specified direction of spread. The basic input values (fuel model, fuel moisture, midflame windspeed, and percent slope) are entered directly.

SITE - Calculates the same values as does DIRECT. However, SITE is designed to help the user estimate fine fuel moisture, wind, and slope. Very site-specific information (temperature, days since precipitation, canopy cover information, etc.) is input to SITE. A major feature of SITE is the capability to estimate moisture of fine, dead fuel.

SIZE - Calculates area and perimeter for a point-source fire that retains a roughly elliptical shape. SIZE can be used independently or be linked with DIRECT or SITE; that is, output from DIRECT or SITE will be used as input to SIZE.

CONTAIN - Calculates attack requirements. Burned area can be predicted, given forward rate of spread, initial area, fire shape length-to-width ratio, and control line construction rate. CONTAIN can also calculate line construction rate needed to hold the burned area to a fixed value, given the other variables listed. CONTAIN can be used either independently or linked with SIZE and either DIRECT or SITE.

SPOT - Calculates maximum spotting distance from a burning pile of debris or from torching trees, given a description of the terrain, forest cover, and windspeed.

DISPATCH - This module is an example of the type of fire behavior prediction that could be made from input values that might be available to a dispatcher. This keyword essentially causes an automatic link between DIRECT, SIZE, and CONTAIN.

The "operation" keywords are INPUT, LIST, CHANGE, and RUN. They are used to enter the input and obtain the output. They do exactly what you would expect them to do. After you type one of these keywords, you will be asked direct questions.

INPUT - All of the input values for the module are asked for.

LIST - The currently stored input values are listed.

CHANGE - You can change individual input values by indicating the line number on the worksheet.

RUN - Calculations are done and results are printed.

Other keywords are CUSTOM and QUIT.

CUSTOM - This keyword must be used, usually at the beginning of a run, if you are going to use custom fuel models. It allows you to specify the name of the file to be attached to this run and to see what is in the file. You can list the numbers and names of the fuel models in the file or the parameters for a specific fuel model. The custom fuel model file is created by the FUEL subsystem (NEWMDL and TSTMDL programs) and can be read but not altered by the BURN subsystem (FIRE1 program).

QUIT - Indicates that you are finished working with the module that you have been in. QUIT takes you back one level in the hierarchy of keywords as described in the next section. If you type QUIT when you are at the first level, the program run will ask if you really want to quit; a positive response will terminate the run. When you terminate the run, the input values that you entered are lost.

Hierarchy of Keywords

The hierarchy of FIRE1 keywords is shown in exhibit 2. Some of the keywords can be entered any time a keyword is requested. These are WORDY, TERSE, PAUSE, NOPAUSE, HELP, KEY, and QUIT. Others can be entered only in the appropriate place. When you are in the WORDY mode, the valid keywords are listed after every keyword request. You can also type KEY to see the list of valid keywords with a brief description of each.

The program will lead you through the logic of the keyword hierarchy. You enter a keyword to specify which module you want to be in. Use the keywords INPUT, LIST, CHANGE, and RUN to enter the input and obtain the output. When you are through with a module, you either type QUIT to return to the previous level in the hierarchy or you type the keyword to link the next module.

SIZE and CONTAIN can be used as independent modules, where you are required to type in every input value. Or they can be linked to other modules, where some of the input values are calculated. When SIZE is linked to DIRECT, it is similar to the setup on the TI-59 CROM (Burgan 1979a). Conversely, the containment program for the TI-59 (Albini and Chase 1980) is like the CONTAIN module of FIRE1 used independently. Allowing any module to be used either independently or linked to other modules when possible gives FIRE1 maximum flexibility.

- FIRE1
  - SITE
    - INPUT,LIST,CHANGE,RUN
    - SIZE[1]
      - INPUT,LIST,CHANGE,RUN
      - CONTAIN[2]
        - INPUT,LIST,CHANGE,RUN
  - DIRECT
    - INPUT,LIST,CHANGE,RUN
    - SIZE[1]
      - INPUT,LIST,CHANGE,RUN
      - CONTAIN[2]
        - INPUT,LIST,CHANGE,RUN
  - SIZE
    - INPUT,LIST,CHANGE,RUN
  - CONTAIN
    - INPUT,LIST,CHANGE,RUN
  - SPOT
    - INPUT,LIST,CHANGE,RUN
  - DISPATCH
    - INPUT,LIST,CHANGE,RUN
  - CUSTOM

Exhibit 2.—FIRE1 keyword hierarchy. TERSE, WORDY, PAUSE, NOPAUSE, HELP, KEY, and QUIT can be entered any time a keyword is requested.

[1]SIZE is a legal keyword here only after a successful RUN

[2]CONTAIN is a legal keyword here only after a successful RUN

Answering Questions

After you use keywords to indicate what you want to do, FIRE1 will ask you questions. The required response may be a value, range of values, or a code. If you enter an improper value, you will get a message, your input will be echoed, and the question will be repeated. You will stay in this loop until the computer is satisfied with your answer.

The following are general guidelines for the FIRE1 program. Page numbers refer to examples in appendix A.

—Valid answers are always listed after the question mark (p.64).

—Input must be entered without imbedded blanks (p.65).

—Integers can be entered with or without a decimal point (p.65).

—If a fractional value makes sense, it can be entered to no more accuracy than tenths (one decimal point) (p.64).

—A range of values is specified by entering the starting value, the ending value, and the step size, separated by commas. Up to 7 values are allowed for some input variables. After you specify the range that you want, the individual values will be printed for your verification. You will have the chance to repeat your input (p.66).

—If a range of values is entered for only one input variable, a list of output values will be printed (p.67). If a range is entered for two input variables, a table of output values will be printed. You will be requested to specify the table variable that you want (p.68). If a range is entered for more than two input variables, you will be warned of an error (p.83).

—If you are in the WORDY mode and the input is a code, definitions are printed under the question (p.74). In the TERSE mode code definitions are not printed (p.75). If you do not remember the code, you can refer to the listings in appendix B.

Appendix B lists the input values for each module, the valid answers, whether a range is allowed, and whether an integer is required. Code definitions are also given. This appendix is for reference. The program will guide you through your choices without the list.

THE BASIS OF THE CALCULATIONS

The FIRE1 program is easy to run. It is possible to quickly generate a lot of fire behavior predictions. It may be tempting to ignore what the computer does between the time RUN is typed and the time results are printed. The timelag will hardly be noticeable, but what happens is important. The computer should not be thought of as a "black box." To be used effectively, the basic assumptions, limitations, and proper application of the models must be understood. This, however, does not mean that it is necessary to study the equations themselves. The mathematical models that are programmed into FIRE1 are generally documented in scientific publications if you are interested in further study. References are included in this paper with the description of each model. A summary of the equations used in BEHAVE is given by Andrews and Morris (in preparation).

The predictions that come from FIRE1 are based on mathematical models that include simplifying assumptions. You must judge the applicability of the results according to how closely the real situation conforms to the idealized model. This section is included to help you make such judgment. A later section is devoted to application.

Rate of Spread and Intensity (SITE and DIRECT)

The SITE and DIRECT modules of the FIRE1 program allow you to predict rate of spread, heat per unit area, fireline intensity, flame length, reaction intensity, effective windspeed, and direction of maximum spread. Although both modules predict the same values, their input is at a different level of resolution and they are designed for different applications. SITE aids the user in estimating fine dead fuel moisture, wind, and slope. Its major feature is the estimation of fine dead fuel moisture from weather and shading information. SITE will be used to make fire behavior predictions in cases where detailed site-specific information is available. On the other hand, DIRECT requires direct input of the basic input values (for example, 1-h fuel moisture). DIRECT may be more useful for general fire behavior predictions and "what if" questions.

The core of the SITE and DIRECT modules and, in fact, of the entire BEHAVE system, is Rothermel's (1972) "A Mathematical Model for Predicting Fire Spread in Wildland Fuels." In the manual on the FUEL subsystem of BEHAVE, Burgan and Rothermel (1984) explain in detail the fire model as it applies to fuel modeling. In this section, I will discuss the basic assumptions and limitations of the fire spread model and explain each output value. The basic input values (fuel model, fuel moisture, windspeed, and slope) will be covered individually in following sections.

ASSUMPTIONS AND LIMITATION OF THE SPREAD MODEL

Some basic assumptions inherent in the mathematical model that predicts fire spread limit its application. There are ways to deal with many of the limitations, but you must be aware of them and avoid using the predictions in situations for which they do not apply. When the fire model is discussed, its limitations

are usually listed (for example, Rothermel 1972; Albini 1976a, 1976b; Burgan 1979a; Rothermel 1983). But the subject is so important that it is covered here also.

Because the model was designed to predict the spread of a fire, the fire model describes fire behavior in the flaming front (fig. 3). The primary driving force in the calculations is the dead fuel less than one-fourth inch in diameter, the fine fuels that carry the fire. Fuels larger then 3 inches in diameter are not included in the calculations at all. Residence time of the flame at a given point is a function only of the characteristic surface-area-to-volume ratio of the fuel array (Anderson 1969). For the 13 standard NFFL fuel models, residence time ranges from 0.11 to 0.34 minute (Rothermel 1983). Burning of larger fuels persists after the initial front has passed, although this is not included in this model.

The fire model is primarily intended to describe fires advancing steadily, independent of the source of ignition. Special care should be taken in applying predictions to prescribed fire where the behavior is affected by the pattern of ignition. Nevertheless, predictions can be used in conjunction with prescribed fire as described in the applications section.

The fire model describes fire spreading through surface fuels. This includes fuel within about 6 feet of the ground and contiguous to the ground. Surface fuels are often classified as grass, brush, litter, or slash (activity fuel). The fire model cannot be applied to ground fires—for example, smoldering duff fires or fires in peat bogs. Nor can the fire model be applied to crown fires where fire spreads from tree to tree independent of the surface fuel. (In some cases regeneration can be considered to be a surface fuel.) The model can identify when conditions are becoming severe enough to expect crowning and spotting.

Fuel, fuel moisture, wind, and slope are assumed to be constant during the time the predictions are to be applied. Because fires almost always burn under nonuniform conditions, length of projection period and choice of fuel must be carefully considered to obtain useful predictions. The more uniform the conditions, the longer the projection time can be. When fire burns from one fuel type to another, such as out of the grass on lower slopes and into timber, the fuel model as well as fuel moisture, slope, and windspeed must be changed. On the other hand, if the fire is burning in and out of two fuel types repeatedly, the two-fuel-model concept should be used. Wind is variable, but often tends to follow daily patterns. This complex problem is thoroughly discussed by Rothermel (1983). Burning conditions change markedly during a 24-hour diurnal cycle, therefore projection times should be limited to 2- to 4-hour periods when conditions can be expected to be reasonably constant.

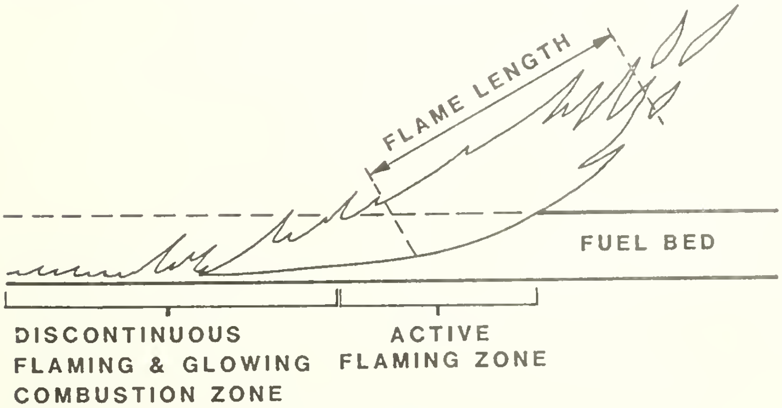

Figure 3.—The active flaming zone in relation to discontinuous flaming and glowing combustion.

INTENSITY

Flame length, fireline intensity, reaction intensity, and heat per unit area are all measures of the intensity of a fire. They have the following units:

flame length, ft
fireline intensity, Btu/ft/s
reaction intensity, Btu/ft^2/min
heat per unit area, Btu/ft^2.

Reaction intensity is a direct output of Rothermel's model (1972), with some revisions by Albini (1976b). **Fireline intensity** was defined by Byram (1959). Using Anderson's (1969) relationship for flame residence time, Rothermel's model can be used to predict Byram's fireline intensity. **Heat per unit area** is obtained from Rothermel's reaction intensity and Anderson's residence time. **Flame length** is directly related to fireline intensity. Flame length and fireline intensity are related to the heat felt by a person standing next to the flame (table 1).

Table 1.—Fire suppression interpretations of flame length and fireline intensity

Flame length	Fireline intensity	Interpretation
Feet	*Btu/ft/s*	
< 4	< 100	Fire can generally be attacked at the head or flanks by persons using handtools. Hand line should hold the fire.
4 - 8	100 - 500	Fires are too intense for direct attack on the head by persons using handtools. Hand line cannot be relied on to hold fire. Equipment such as plows, dozers, pumpers, and retardant aircraft can be effective.
8 - 11	500 - 1,000	Fires may present serious control problems—torching out, crowning, and spotting. Control efforts at the fire head will probably be ineffective.
> 11	> 1,000	Crowning, spotting, and major fire runs are probable. Control efforts at head of fire are ineffective.

Equations showing the relationships between the three intensities and flame length are given in exhibit 3. **Reaction intensity** is the heat released **per minute** from a square foot of fuel while in the flaming zone. **Heat per unit area** is the heat released from a square foot of fuel while the flaming zone is in that area. Heat per unit area is equal to the reaction intensity times the residence time. **Fireline intensity** is the heat released **per second** from a foot-wide section of fuel extending from the front to the rear of the flaming zone. Fireline intensity is equal to the reaction intensity times the flame depth or heat per unit area times the rate of spread. **Flame length** is a function of fireline intensity.

$$t_r = \frac{384}{\sigma}$$

$$D = R\, t_r$$

$$H_A = I_R\, t_r$$

$$I_B = \frac{I_R\, D}{60}$$

$$= \frac{I_R\, R\, t_r}{60}$$

$$= \frac{H_A\, R}{60}$$

$$F_L = 0.45\, I_B^{0.46}$$

where

- σ = characteristic surface-area-to-volume ratio of the fuel array, ft^2/ft^3
- t_r = flame residence time, min
- R = rate of spread, ft/min (BURN uses ch/h for rate of spread)
- D = flame depth, ft
- I_R = reaction intensity, $Btu/ft^2/min$
- H_A = heat per unit area, Btu/ft^2
- I_B = Byram's fireline intensity, Btu/ft/s (the 60 is required for the minutes-to-seconds conversion)
- F_L = flame length, ft.

Exhibit 3.—Relationships among reaction intensity, heat per unit area, fireline intensity, and flame length.

The fire characteristics chart (Andrews and Rothermel 1982) illustrates the relationship between rate of spread, heat per unit area, fireline intensity, and flame length. The chart allows you to plot the four values as a single point. DIRECT output values in exhibit 4A are plotted on a fire characteristics chart in exhibit 4B. Notice that as wind increases, rate of spread, flame length, and fireline intensity increase, but heat per unit area remains constant.

RATE OF SPREAD

In the BURN subsystem, the units of rate of spread are chains per hour. In the FUEL subsystem, the units are feet per minute. The values are nearly equal. Rate of spread in feet per minute is equal to 1.1 times rate of spread in chains per hour. The difference is due to the basic use of the two subsystems. FUEL is a development tool, and rate of spread is generally published in feet per minute. In addition, chains per hour is awkward for the graphics employed in the TSTMDL program. BURN uses chains per hour because these units are generally used in operational settings. The TI-59, nomograms, and S-390 tables also produce rate of spread in chains per hour.

When low-intensity fires burn under high windspeeds, the fire front may begin to "finger" rather than spread with a uniform front. To avoid overprediction of this type of fire, a limit is put on the effective windspeed that is used in the calculations. This value is a function of reaction intensity as described by

A.
```
 1--FUEL MODEL                         13 -- HEAVY LOGGING SLASH
 2--1-HR FUEL MOISTURE, %              8.0
 3--10-HR FUEL MOISTURE, %             8.0
 4--100-HR FUEL MOISTURE, %            8.0
 7--MIDFLAME WINDSPEED, MI/H           2.0    6.0   10.0
 8--PERCENT SLOPE                     30.0
 9--DIRECTION OF WIND VECTOR           0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD                0.0   (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL
```

MIDFLAME WIND (MI/H)	RATE OF SPREAD (CH/H)	HEAT PER UNIT AREA (BTU/SQ.FT)	FIRELINE INTENSITY (BTU/FT/S)	FLAME LENGTH (FT)	REACTION INTENSITY (BTU/SQFT/M)	EFFECT. WIND (MI/H)
2.	8.	3053.	464.	7.6	9214.	2.9
6.	19.	3053.	1080.	11.2	9214.	6.8
10.	31.	3053.	1763.	14.0	9214.	10.7

B.

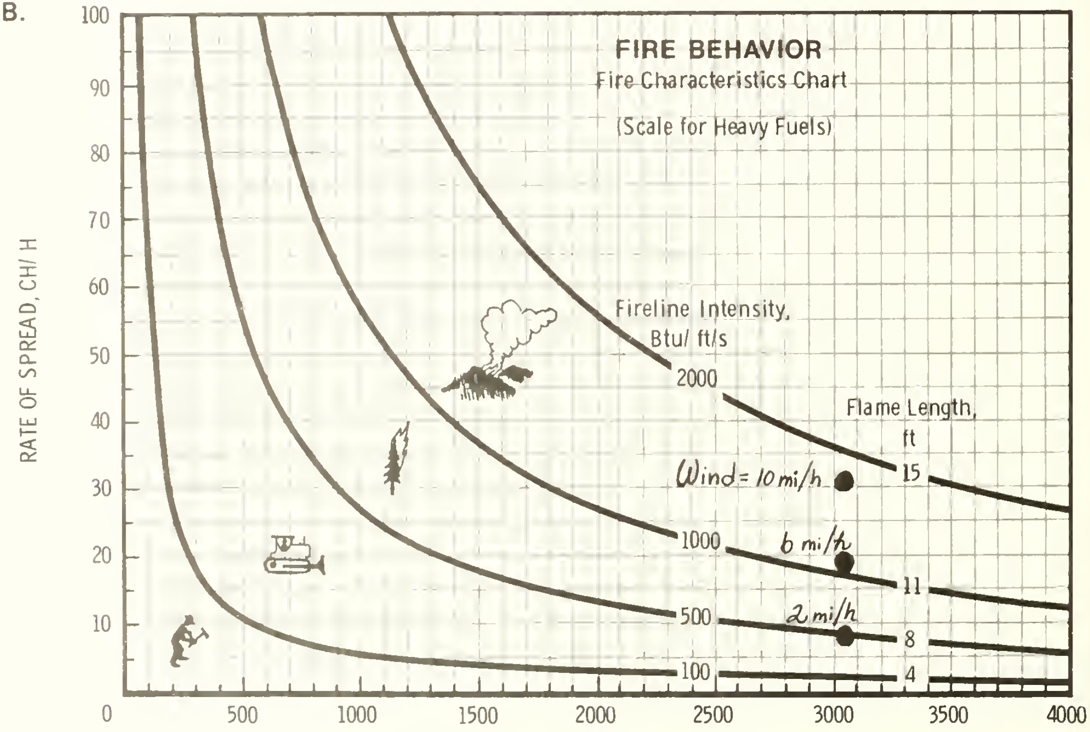

Exhibit 4.—Rate of spread, heat per unit area, fireline intensity, and flame length for three windspeeds plotted on a fire characteristics chart.

Rothermel (1972, p. 33). The TI-59 and the nomograms apply this limit to windspeed alone, whereas the BEHAVE programs put a limit on the combination of wind and slope (effective windspeed). This may lead to a slight difference in predictions. As illustrated in exhibit 5, when you reach this wind limit, the affected values are starred and a footnote is printed. The values for effective windspeed are the ones that are used in the calculations of rate of spread, fireline intensity, and flame length.

```
 1---FUEL MODEL                      1  -- SHORT GRASS (1 FT)
 2---1-HR FUEL MOISTURE, %          6.0
 7---MIDFLAME WINDSPEED, MI/H       0.0    3.0    6.0    9.0   12.0
 8---PERCENT SLOPE                  0.0
 9---DIRECTION OF WIND VECTOR       0.0
10---DIRECTION OF SPREAD            0.0   (DIRECTION OF MAX SPREAD)
     CALCULATIONS
      DEGREES CLOCKWISE
       FROM THE WIND VECTOR


MIDFLAME  I RATE OF   HEAT PER     FIRELINE   FLAME    REACTION   EFFECT.
  WIND    I SPREAD   UNIT AREA   INTENSITY   LENGTH   INTENSITY    WIND
 (MI/H)   I (CH/H) (BTU/SQ.FT) (BTU/FT/S)   (FT) (BTU/SQFT/M)  (MI/H)
          I
          I
   0.     I    4.         91.          7.      1.1       826.       0.0
          I
   3.     I   35.         91.         59.      2.9       826.       3.0
          I
   6.     I  135.         91.        224.      5.4       826.       6.0
          I
   9.     I  270.         91.        449.      7.5       826.       8.4*
          I
  12.     I  270.         91.        449.      7.5       826.       8.4*

          * MEANS YOU HIT THE WIND LIMIT.
```

Exhibit 5.—Windspeed effect is limited to avoid overprediction of low-intensity fires. In this example, 8.4 mi/h is the upper limit, so 9 and 12 mi/h windspeeds have the same effect as 8.4 mi/h wind.

DIRECTION OF SPREAD

The basic fire model (Rothermel 1972) assumes that wind is blowing directly upslope; that is, wind and slope both have an increasing effect on fire spread in the same direction. FIRE1 allows you to specify the direction of a cross-slope wind and calculate fire behavior in the direction of maximum spread. In addition, it is possible to obtain predictions for any other direction of spread (Andrews and Morris in preparation).

Directions are entered as degrees clockwise from upslope (when there is a slope). Direction of the wind vector is the direction of the effect of wind on spread, that is, the direction that the wind is blowing to. If the wind is blowing directly upslope, the direction of the wind vector is entered as 0; if the wind is blowing directly downslope, 180 is entered. Figure 4 illustrates directions from 0 to 360 for specifying wind and spread directions. This figure is just for your reference; any value from 0 to 360 can be entered.

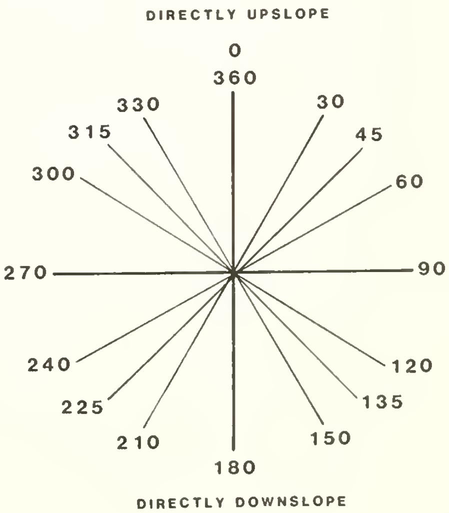

Figure 4.—Diagram of degrees clockwise from uphill for specifying direction of the wind vector and spread direction. (Any value from 0 to 360 can be entered.)

Whenever slope and wind are nonzero, wind direction is requested. Then you are asked whether you want the predictions for the direction of maximum spread. If you answer "no," you will be asked to specify the spread direction, and predictions will be for that specified direction. An example is shown in exhibit 6.

```
1--FUEL MODEL                          2 -- TIMBER (GRASS AND UNDERSTORY)
2--1-HR FUEL MOISTURE, %             2.0
3--10-HR FUEL MOISTURE, %            3.0
4--100-HR FUEL MOISTURE, %           4.0
5--LIVE HERBACEOUS MOIS, %         100.0
7--MIDFLAME WINDSPEED, MI/H          5.0
8--PERCENT SLOPE                    20.0
9--DIRECTION OF WIND VECTOR         60.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD              0.0   60.0 120.0
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL

SPREAD  I RATE OF   HEAT PER    FIRELINE   FLAME    REACTION   EFFECT.
DIRECT. I SPREAD   UNIT AREA   INTENSITY  LENGTH  INTENSITY    WIND
 (DEG)  I (CH/H)  (BTU/SQ.FT) (BTU/FT/S)   (FT)  (BTU/SQFT/M) (MI/H)
        I
        I
   0.   I   10.       598.        111.      3.9     4333.       1.8
        I
  60.   I   50.       598.        546.      8.2     4333.       5.1
        I
 120.   I    9.       598.         95.      3.7     4333.       1.6
```

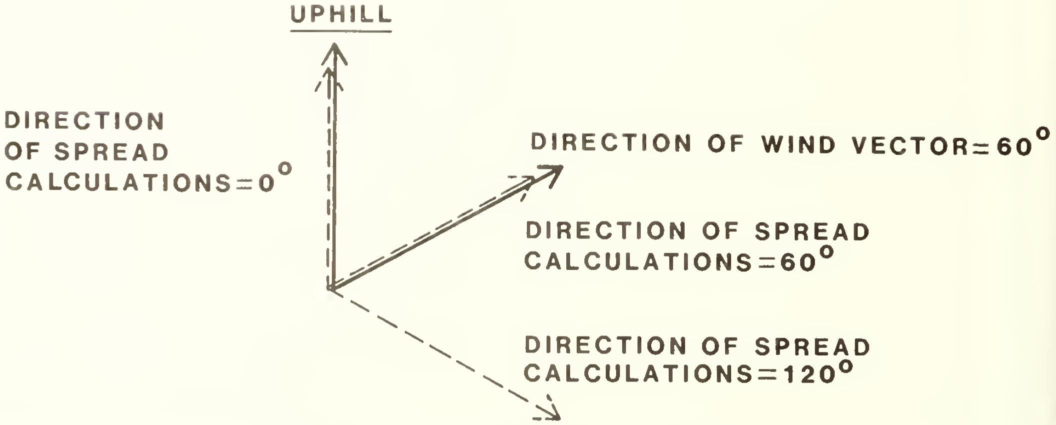

Exhibit 6.—DIRECT run, where the direction for the spread calculations is input. (Arrows indicate direction. Lengths are not relevant.)

On the other hand, you can indicate that you **do** want predictions for the direction of maximum spread. When windspeed, slope, and wind direction are all nonzero (that is, a cross-slope wind), then the direction of maximum spread will be calculated and given as an output value as shown in the example in exhibit 7. Otherwise, the direction of maximum spread is obviously zero and will be printed with the input because no additional calculations are necessary.

Often you will want predictions for fire spreading directly upslope with the wind. When this is the case, enter the wind direction as zero and specify that you want predictions for the direction of maximum spread. The direction of maximum spread will be zero also.

```
1--FUEL MODEL                          2 -- TIMBER (GRASS AND UNDERSTORY)
2---1-HR FUEL MOISTURE, %            2.0
3---10-HR FUEL MOISTURE, %           3.0
4---100-HR FUEL MOISTURE, %          4.0
5---LIVE HERBACEOUS MOIS, %        100.0
7---MIDFLAME WINDSPEED, MI/H         2.0    8.0
8---PERCENT SLOPE                   40.0
9---DIRECTION OF WIND VECTOR        50.0
     DEGREES CLOCKWISE
      FROM UPHILL
10---DIRECTION OF SPREAD            DIRECTION OF MAXIMUM SPREAD
     CALCULATIONS                     TO BE CALCULATED
     DEGREES CLOCKWISE
      FROM UPHILL


MIDFLAME I RATE OF   HEAT PER    FIRELINE   FLAME    REACTION   EFFECT.  MAX
  WIND   I SPREAD   UNIT AREA   INTENSITY  LENGTH  INTENSITY    WIND   SPREAD
 (MI/H)  I (CH/H) (BTU/SQ.FT) (BTU/FT/S)   (FT) (BTU/SQFT/M)(MI/H)   DIREC
         I                                                          (DEG)
         I
   2.    I   22.        598.         243.      5.6      4333.      3.1     20.
         I
   8.    I  120.        598.        1312.     12.2      4333.      8.3     45.
```

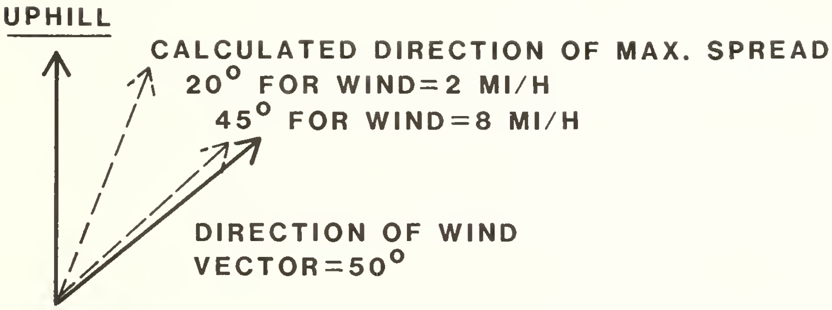

Exhibit 7.—DIRECT run, with cross-slope wind. The direction of maximum spread is calculated. (Arrows indicate direction. Lengths are not relevant.)

EFFECTIVE WINDSPEED

Effective windspeed is a combination of the effects of wind and slope. It is a function of midflame wind, slope, and fuel model as illustrated in exhibits 8A and 8B. The two runs are identical except that exhibit 8A is for fuel model 3 (tall grass) and exhibit 8B is for fuel model 1 (short grass). For fuel model 3, the effective windspeed is 3 mi/h for no wind and 60 percent slope and also for a 3-mi/h wind and no slope (underlined values). That is, for this particular example, no wind and a 60 percent slope is effectively the same as 3 mi/h wind on the flat. Effective windspeed lets you see the relative effects of wind and slope on the predictions. Notice that for a 6-mi/h wind and 80 percent slope, the effective windspeed is 9.0 mi/h for fuel model 3 and 8.1 mi/h for fuel model 1

A.

```
1--FUEL MODEL                       3  -- TALL GRASS (2.5 FT)
2--1-HR FUEL MOISTURE, %           6.0
7--MIDFLAME WINDSPEED, MI/H        0.0    3.0    6.0
8--PERCENT SLOPE                   0.0   20.0   40.0   60.0   80.0
9--DIRECTION OF WIND VECTOR        0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD            0.0   (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL

==============================================================================
EFFECTIVE WINDSPEED, MI/H
==============================================================================
MIDFLAME I          PERCENT SLOPE
  WIND   I
 (MI/H)  I      0.      20.      40.      60.      80.
         I-----------------------------------------------------------------
         I
   0.    I     0.0      0.6      1.6      3.0      4.6
         I
   3.    I     3.0      3.2      4.0      5.1      6.5
         I
   6.    I     6.0      6.2      6.8      7.8      9.0
```

B.

```
1--FUEL MODEL                       1  -- SHORT GRASS (1 FT)
2--1-HR FUEL MOISTURE, %           6.0
7--MIDFLAME WINDSPEED, MI/H        0.0    3.0    6.0
8--PERCENT SLOPE                   0.0   20.0   40.0   60.0   80.0
9--DIRECTION OF WIND VECTOR        0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD            0.0   (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL

==============================================================================
EFFECTIVE WINDSPEED, MI/H
==============================================================================
MIDFLAME I          PERCENT SLOPE
  WIND   I
 (MI/H)  I      0.      20.      40.      60.      80.
         I-----------------------------------------------------------------
         I
   0.    I     0.0      1.4      2.8      4.2      5.5
         I
   3.    I     3.0      3.3      4.1      5.1      6.2
         I
   6.    I     6.0      6.2      6.6      7.2      8.1
```

Exhibit 8.—Comparison of effective windspeed under the same conditions for (A) fuel model 3 and (B) fuel model 1.

(circled values). Notice also that for no wind the relative magnitudes for effective windspeed are reversed for the two fuel models, 4.6 mi/h for fuel model 3 and 5.5 mi/h for fuel model 1 (boxed values).

The effective windspeed printed in the output is for the direction of the spread calculations. For example, in exhibit 6, although wind and slope were assigned single values, the effective windspeed varies with the direction of the spread calculations.

Fuel Models

A fuel model is a set of numerical values that describes a fuel type for the mathematical model that predicts spread rate and intensity (Rothermel 1972). The parameters that can be varied in a fuel model are:

— loading for each fuel particle diameter size class, lb/ft^2

— surface-area-to-volume ratio for each size class, ft^2/ft^3

— fuel bed depth, ft

— heat content of fuel, Btu/lb

— moisture of extinction, percent.

Until now there has essentially been a choice of 13 stylized fire behavior fuel models (Anderson 1982). These are generally referred to as NFFL (Northern Forest Fire Laboratory, recently renamed Intermountain Fire Sciences Laboratory) and sometimes as FBO (Fire Behavior Officer) fuel models. Some special-purpose fuel models have been developed for critical fuel types, including southern California chaparral (Rothermel and Philpot 1973) and palmetto-gallberry (Hough and Albini 1978). The limited number of fuel models has handicapped fire behavior prediction. BEHAVE allows individual users to design custom fire behavior fuel models to represent local fuel conditions. Burgan and Rothermel (1984) describe the FUEL subsystem of BEHAVE and the custom fuel model building process.

NFFL FUEL MODELS

Do not design a custom fuel model until you are convinced that none of the 13 meet your needs. The 13 NFFL fuel models are described by Anderson (1982). Color photographs illustrate examples for each model. Rothermel (1983) lists considerations in selecting a fuel model (which strata is likely to carry the fire, how much green fuel is present, etc.) and provides a selection key. He also describes the two-fuel-model concept. Table 2 shows the parameters for the 13 fuel models (Anderson 1982) and calculated fuel model parameters as described by Burgan and Rothermel (1984). Predicted fire behavior for the 13 models under two sets of environmental conditions is given in exhibit 9.

If you use only the 13 NFFL fuel models in FIRE1, you can ignore the FUEL subsystem of BEHAVE and fuel model files. The 13 standard fuel models are stored as a part of the FIRE1 program.

Table 2.—Fuel model parameters and calculated fuel bed descriptors for the standard 13 NFFL fuel models[1]

Fuel model	Typical fuel complex	Surface-area-to-volume ratio(ft^{-1})/fuel loading (tons/acre) 1-h	10-h	100-h	Live	Fuel bed depth	Moisture of extinction dead fuels	Characteristic surface area-to-volume ratio	Packing ratio	Packing ratio/Optimum packing ratio
						Ft	*Percent*	*Ft^{-1}*		
	Grass and grass-dominated									
1	Short grass (1 ft)	3,500/0.74	—	—	—	1.0	12	3,500	0.00106	0.25
2	Timber (grass and understory)	3,000/2.00	109/1.00	30/0.50	1,500/0.50	1.0	15	2,784	.00575	1.14
3	Tall grass (2.5 ft)	1,500/3.01	—	—	—	2.5	25	1,500	.00172	.21
	Chaparral and shrub fields									
4	Chaparral (6 ft)	2,000/5.01	109/4.01	30/2.00	1,500/5.01	6.0	20	1,739	.00383	.52
5	Brush (2 ft)	2,000/1.00	109/0.50	—	1,500/2.00	2.0	20	1,683	.00252	.33
6	Dormant brush, hardwood slash	1,750/1.50	109/2.50	30/2.00	—	2.5	25	1,564	.00345	.43
7	Southern rough	1,750/1.13	109/1.87	30/1.50	1,500/0.37	2.5	40	1,562	.00280	.34
	Timber litter									
8	Closed timber litter	2,000/1.50	109/1.00	30/2.50	—	.2	30	1,889	.03594	5.17
9	Hardwood litter	2,500/2.92	109/0.41	30/0.15	—	.2	25	2,484	.02500	4.50
10	Timber (litter and understory)	2,000/3.01	109/2.00	30/5.01	1,500/2.00	1.0	25	1,764	.01725	2.35
	Slash									
11	Light logging slash	1,500/1.50	109/4.51	30/5.51	—	1.0	15	1,182	.01653	1.62
12	Medium logging slash	1,500/4.01	109/14.03	30/16.53	—	2.3	20	1,145	.02156	2.06
13	Heavy logging slash	1,500/7.01	109/23.04	30/28.05	—	3.0	25	1,159	.02778	2.68

[1]Heat content = 8,000 Btu/lb for all fuel models.

1-h moisture, %	3		12	
10-h moisture, %	4		13	
100-h moisture, %	5		14	
live moisture, %	70		170	
midflame windspeed, mi/h	4		4	
slope, %	30		30	
Fuel model	**Rate of spread (ch/h)**	**Flame length (ft)**	**Rate of spread (ch/h)**	**Flame length (ft)**
1	97	4.9	0	0.0
2	40	7.1	15	3.6
3	140	15.9	75	10.2
4	100	24.1	20	7.4
5	33	7.5	5	1.7
6	41	7.3	22	4.7
7	35	7.0	15	4.1
8	2	1.3	1	.8
9	10	3.4	5	2.2
10	11	6.3	4	3.6
11	7	4.1	3	2.2
12	17	9.9	9	6.6
13	21	12.9	11	8.5

Exhibit 9.—Predicted rate of spread and flame length for the 13 NFFL fuel models under two sets of environmental conditions.

CUSTOM FUEL MODELS

Custom fire behavior fuel models are developed and stored in a file using the FUEL subsystem (Burgan and Rothermel 1984). (The particulars of fuel model files are covered in appendix C.) To use a custom fuel model with the FIRE1 program, you must use the keyword CUSTOM to specify the name of the file where the custom fuel models are stored. CUSTOM also allows you to see what is stored in the file. An example is shown in exhibit 10. You can either list the numbers and names of fuel models in the file or you can list the parameters for a specific fuel model. You cannot change fuel model parameters with the FIRE1 program. Once you specify the name of the file where your custom fuel models are saved, they are referenced by number in response to the question: FUEL MODEL ? 1-99. Each user can have a private file and can therefore assign any number from 14 to 99 and name to a custom model.

```
TYPE 'CUSTOM' IF YOU ARE GOING TO USE CUSTOM FUEL MODELS.

FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>CUSTOM

A FUEL MODEL FILE IS NOT CURRENTLY ATTACHED TO THIS RUN.

FUEL MODEL FILE NAME ?
>PATDAT

THERE IS NO FUEL MODEL FILE BY THIS NAME.

DO YOU WANT TO TRY ANOTHER FILE NAME ? Y-N
>Y

FUEL MODEL FILE NAME ?
>PAT.DAT

CUSTOM FUEL MODEL FILE NAME: PAT.DAT
FILE DESCRIPTION:
   EXAMPLE FOR USERS MANUAL

DO YOU WANT A LIST OF THE FUEL MODELS THAT ARE STORED
IN THE FILE ? Y-N
>Y


CUSTOM FUEL MODEL FILE NAME: PAT.DAT
FILE DESCRIPTION:
   EXAMPLE FOR USERS MANUAL

              NUMBER  FUEL MODEL NAME

  (STATIC)     23      STATIC GRASS
  (DYNAMIC)    25      DYNAMIC GRASS

DO YOU WANT THE PARAMETER LIST FOR A SPECIFIC
FUEL MODEL ? Y-N
>Y

FUEL MODEL ? 14-99
>23


STATIC CUSTOM MODEL 23 -- STATIC GRASS
FROM FILE NAME: PAT.DAT
FILE DESCRIPTION:
   EXAMPLE FOR USERS MANUAL

     LOAD (T/AC)            S/V RATIOS                    OTHER
  ------------------     ------------------    ---------------------------------
  1 HR            1.00   1 HR          3500.   DEPTH (FEET)                 1.00
  10 HR           0.00   LIVE HERB     3500.   HEAT CONTENT (BTU/LB)     8000.
  100 HR          0.00   LIVE WOODY       0.   EXT MOISTURE (%)            15.
  LIVE HERB       1.00   S/V = (SQFT/CUFT)
  LIVE WOODY      0.00

  EXPOSED FUEL WIND ADJUSTMENT FACTOR =0.4

DO YOU WANT THE PARAMETER LIST FOR A SPECIFIC
FUEL MODEL ? Y-N
>Y

FUEL MODEL ? 14-99
>25
```

Exhibit 10.—Example use of the keyword CUSTOM. A custom fuel model file is attached to the run and its contents are examined.

```
DYNAMIC CUSTOM MODEL 25 -- DYNAMIC GRASS
FROM FILE NAME: PAT.DAT
FILE DESCRIPTION:
   EXAMPLE FOR USERS MANUAL

      LOAD (T/AC)              S/V RATIOS                    OTHER
  ---------------------    ---------------------    ---------------------------------
  1 HR            1.00     1 HR          3500.     DEPTH (FEET)                1.00
  10 HR           0.00     LIVE HERB     3500.     HEAT CONTENT (BTU/LB)      8000.
  100 HR          0.00     LIVE WOODY       0.     EXT MOISTURE (%)             15.
  LIVE HERB       1.00     S/V = (SQFT/CUFT)
  LIVE WOODY      0.00

  EXPOSED FUEL WIND ADJUSTMENT FACTOR =0.4

DO YOU WANT THE PARAMETER LIST FOR A SPECIFIC
FUEL MODEL ? Y-N
>N

FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
```

Exhibit 10. (Con.)

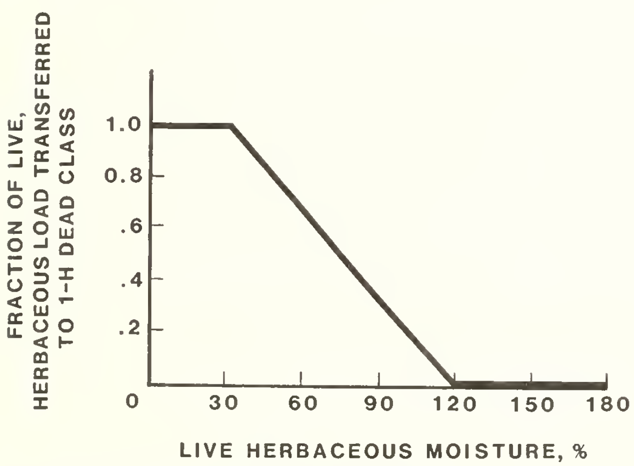

Figure 5.—The fraction of live herbaceous fuel in a dynamic fuel model that is transferred to the 1-h dead class is a function of live herbaceous fuel moisture.

Custom fuel models can be either static or dynamic. The standard 13 models are all static, that is, the fuel model does not change. Dynamic fuel models are meant to account for curing of herbaceous fuels (Burgan 1979b). Load is transferred from the live herbaceous class to the 1-hour timelag dead class (1-h) as a function of the live herbaceous fuel moisture content. The transfer function is shown in figure 5. When the moisture content is greater than 120 percent, all of the fuel that can be in the live herbaceous class remains in that class. When the moisture is 30 percent, all of the live herbaceous load has been transferred to the 1-h dead class. At intermediate values, a fraction of the load has been transferred. For example, when the live herbaceous moisture is 90 percent, 33 percent of the original live herbaceous load has been transferred to the 1-h class. When the fuel model parameters are listed, all of the "transferrable" load is in the live herbaceous class. Notice that in exhibit 10, the parameters for models 23 and 25 are the same, but 23 is static and 25 is dynamic.

The DIRECT runs in exhibit 11 show the differences in fire behavior prediction with changes in live herbaceous fuel moisture. When live herbaceous fuel moisture is 120 percent or greater, the predictions are the same because the models are the same—all of the herbaceous load of the dynamic model 25 is still in the live class. At moisture contents less than 120 percent, some of the live load has been transferred to the 1-h dead class; therefore the predictions are different. The dynamic model 25 has more fuel in the 1-h class, thus rate of spread and flame length predictions are higher.

```
1--FUEL MODEL                          23 -- STATIC GRASS
2--1-HR FUEL MOISTURE, %                5.0
5--LIVE HERBACEOUS MOIS, %             30.0   60.0   90.0  120.0  150.0
7--MIDFLAME WINDSPEED, MI/H             5.0
8--PERCENT SLOPE                       10.0
9--DIRECTION OF WIND VECTOR             0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD                 0.0   (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL

 LIVE    I RATE OF   HEAT PER    FIRELINE   FLAME    REACTION   EFFECT.
 HERB    I SPREAD   UNIT AREA   INTENSITY  LENGTH   INTENSITY    WIND
 MOIS    I (CH/H)  (BTU/SQ.FT) (BTU/FT/S)   (FT)  (BTU/SQFT/M)  (MI/H)
 (%)     I
         I
 30.     I    80.        325.        477.      7.7      2961.       5.0
         I
 60.     I    53.        293.        283.      6.0      2674.       5.0
         I
 90.     I    40.        284.        208.      5.2      2591.       5.0
         I
120.     I    32.        277.        163.      4.7      2525.       5.0
         I
150.     I    25.        251.        114.      4.0      2290.       5.0
```

```
1--FUEL MODEL                          25 -- DYNAMIC GRASS
2--1-HR FUEL MOISTURE, %                5.0
5--LIVE HERBACEOUS MOIS, %             30.0   60.0   90.0  120.0  150.0
7--MIDFLAME WINDSPEED, MI/H             5.0
8--PERCENT SLOPE                       10.0
9--DIRECTION OF WIND VECTOR             0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD                 0.0   (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL

 LIVE    I RATE OF   HEAT PER    FIRELINE   FLAME    REACTION   EFFECT.
 HERB    I SPREAD   UNIT AREA   INTENSITY  LENGTH   INTENSITY    WIND
 MOIS    I (CH/H)  (BTU/SQ.FT) (BTU/FT/S)   (FT)  (BTU/SQFT/M)  (MI/H)
 (%)     I
         I
 30.     I   105.        291.        558.      8.3      2651.       5.0
         I
 60.     I    85.        316.        492.      7.8      2883.       5.0
         I
 90.     I    53.        302.        295.      6.2      2754.       5.0
         I
120.     I    32.        277.        163.      4.7      2525.       5.0
         I
150.     I    25.        251.        114.      4.0      2290.       5.0
```

Exhibit 11.—Example DIRECT run showing the effect of dynamic load transfer on the predictions.

NFDRS FUEL MODELS

The fact that there are 20 standard NFDRS fuel models (Deeming and others 1977) as well as 13 standard (NFFL) fire behavior fuel models (Anderson 1982) has caused confusion. Use of NFDRS fuel models in BEHAVE can cause serious problems. Reasons are described in appendix D along with a summary of similarities and differences between NFDRS and BEHAVE.

TWO-FUEL-MODEL CONCEPT

When an area is covered by two very different fuel types in patches, it may not be possible to design a custom model to fit the situation. In this case, the two-fuel-model concept may be appropriate. Two fuel models and their relative percentages of cover are specified. When a custom fuel model is used, it should have been designed with the assumption that the fuel type covers the whole area. The percent cover input in FIRE1 takes care of the weighting by percent cover.

An example run using the two-fuel-model concept is shown in exhibit 12. Separate calculations are done for each of the fuel models; then the rate of spread weighted by percent cover is calculated. The fire speeds up and slows down as it burns through the two fuel models, effectively averaging the rate of spread over the projection period. On the other hand, flame length and intensity are not averaged. Part of the area has one flame length and the rest of the area has another flame length. Valuable information would be lost, especially in terms of suppression interpretations, if the flame lengths were averaged.

When SIZE is linked to SITE or DIRECT and the two-fuel-model concept is being used, the effective windspeed for the fuel model covering the greatest area and the weighted rate of spread are used in the area and perimeter calculations. The maximum of the flame length values for the two fuel models is used for the suppression interpretations for the link to CONTAIN.

```
 1--TWO FUEL MODEL CONCEPT      70%  2 -- TIMBER (GRASS AND UNDERSTORY)
                                30% 10 -- TIMBER (LITTER AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %        4.0   6.0   8.0
 3--10-HR FUEL MOISTURE, %       5.0
 4--100-HR FUEL MOISTURE, %      5.0
 5--LIVE HERBACEOUS MOIS, %    100.0
 6--LIVE WOODY MOISTURE, %     100.0
 7--MIDFLAME WINDSPEED, MI/H     6.0
 8--PERCENT SLOPE               10.0
 9--DIRECTION OF WIND VECTOR     0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD          0.0   (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL

FUEL MODEL  2   (70%)

  1-HR   I RATE OF  HEAT PER   FIRELINE  FLAME   REACTION  EFFECT.
  MOIS   I SPREAD  UNIT AREA  INTENSITY  LENGTH  INTENSITY   WIND
  (%)    I (CH/H) (BTU/SQ.FT) (BTU/FT/S)  (FT) (BTU/SQFT/M) (MI/H)
         I
         I
   4.    I   55.      512.       519.      8.0     3713.      6.0
         I
   6.    I   49.      477.       430.      7.3     3460.      6.0
         I
   8.    I   45.      460.       382.      6.9     3336.      6.0
```

Exhibit 12.—DIRECT run illustrating the two-fuel-model concept. (con.)

FUEL MODEL 10 (30%)

1-HR MOIS (%)	RATE OF SPREAD (CH/H)	HEAT PER UNIT AREA (BTU/SQ.FT)	FIRELINE INTENSITY (BTU/FT/S)	FLAME LENGTH (FT)	REACTION INTENSITY (BTU/SQFT/M)	EFFECT. WIND (MI/H)
4.	12.	1386.	309.	6.3	6366.	6.1
6.	11.	1284.	259.	5.8	5898.	6.1
8.	10.	1217.	227.	5.5	5589.	6.1

FUEL MODEL 2 (70%) FUEL MODEL 10 (30%)

1-HR MOIS (%)	WEIGHTED RATE OF SPREAD (CH/H)
4.0	42.
6.0	38.
8.0	35.

FUEL PARTICLE SIZE CLASSES

The 13 NFFL fuel models were limited to one live and three dead (1-h, 10-h, 100-h) fuel classes. Custom fuel models also have three dead classes but allow for two live classes, herbaceous and woody. For consistency, the live fuel in the 13 models has been classified as either herbaceous or woody. Fuel model 2 has live herbaceous fuel. Models 4, 5, 7, and 10 have live woody fuel. The other models (1, 3, 6, 8, 9, 11, 12, 13) have no live fuel. The 13 fuel models are all static, so the classification of live fuel does not affect the calculations. That is, the live fuel moisture will have the same effect on the predictions whether it is woody or herbaceous because there is no transfer of load to the dead class. Nevertheless, because the moisture content will be requested, stored, and printed as either herbaceous or woody, you should be aware of the classification.

Fuel Moisture

Fuel moisture content is a critical variable in predicting fire behavior. Fuel models consist of as many as three dead and two live classes of fuel. A moisture value must be assigned to each class in the fuel model that is currently being used. The DIRECT module requires direct input of fuel moisture values. The most prominent feature of the SITE module is its ability to estimate fine dead fuel moisture from weather and shading conditions.

LIVE FUEL MOISTURE

Live fuels are classified as either herbaceous or woody. Woody fuel includes shrub foliage and twigs less than one-fourth inch in diameter. Herbaceous fuel includes nonwoody plants such as grasses and forbs. If the fuel model is "dynamic," a portion of the herbaceous fuel, based on its moisture content, is considered dead. This process is explained in a previous section on fuel models. If the fuel model is "static," then there is effectively no difference between woody and herbaceous fuels as far as the mathematical model is concerned. If there are no truly herbaceous fuels in a fuel model, then a custom fuel model can be built with one of the two classes of live fuel used for the foliage and one for the twigs, thereby allowing different moisture values to be used for each class.

As noted by Rothermel (1983), "Live fuel moisture values are a result of physiological changes in the plant. These are mainly due to the time of the season, precipitation events, the temperature trend, and the species." In FIRE1,

determination of an appropriate live fuel moisture is up to the user. If no other information is available, live fuel moisture can be estimated by a table of indicators. SITE will print this table upon request (exhibit 13). Direct sampling and measurement of live fuel moisture will give the best estimate. This may be worth the effort for critical prescribed burns. In southern California where fire behavior is especially dependent upon live fuel moisture, there is a system of collection and reporting of live fuel moisture throughout the season (Countryman and Dean 1979). These values are collected for direct input to the NFDRS. They are available for BEHAVE input. Calculated moisture values from the NFDRS can also be used in BEHAVE; however, care must be taken in applying them in mountainous terrain where elevation and aspect will result in moisture values far different from those taken at valley weather stations.

```
(9) DO YOU WANT TO SEE THE LIVE FUEL MOISTURE GUIDELINES ? Y-N
>Y

IF DATA ARE UNAVAILABLE FOR ESTIMATING LIVE FUEL
MOISTURE, THE FOLLOWING ROUGH ESTIMATES CAN BE USED.

     300% = FRESH FOLIAGE, ANNUALS DEVELOPING,
            EARLY IN GROWING CYCLE

     200% = MATURING FOLIAGE, STILL DEVELOPING
            WITH FULL TURGOR

     100% = MATURE FOLIAGE, NEW GROWTH COMPLETE AND
            COMPARABLE TO OLDER PERENNIAL FOLIAGE

      50% = ENTERING DORMANCY, COLORATION STARTING,
            SOME LEAVES MAY HAVE DROPPED FROM STEM

(9) LIVE WOODY MOISTURE, % ? 30-300
>80
```

Exhibit 13.—Live fuel moisture guidelines that can be printed by SITE upon request.

An example of the effect of live fuel moisture on the predictions for fuel model 5 is given in exhibit 14. Notice that in this example when live woody moisture increases from 40 to 80 percent, the difference in fire behavior is significant; and when moisture increases from 240 to 280 percent there is little change in fire behavior. Notice also that when the moisture is 160 percent or greater, the heat per unit area and reaction intensity remain constant, but rate of spread continues to decrease. When the live fuel moisture is low, it burns and contributes to the rate of fire spread. When the moisture reaches a critical level (the calculated live fuel moisture of extinction [Albini 1976b, p. 16]), however, the live fuel does not burn, but continues to act as a heat sink, lowering the rate of spread.

DEAD FUEL MOISTURE

Dead fuels are categorized according to timelag, based on the length of time required for a fuel particle to change moisture by a specified amount when subjected to a change in its environment. Fine dead fuel less than one-fourth inch in diameter comprises the 1-hour timelag (1-h) class. This includes needles, leaves, cured herbaceous plants, and fine dead stems. Dead fuel one-fourth to 1 inch in diameter is 10-h; 1- to 3-inch fuel is 100-h. Fuels larger than 3 inches in diameter are not included in the calculations for spread and intensity.

```
 1--FUEL MODEL                    5 -- BRUSH (2 FT)
 2--1-HR FUEL MOISTURE, %        5.0
 3--10-HR FUEL MOISTURE, %       9.0
 6--LIVE WOODY MOISTURE, %      40.0  80.0 120.0 160.0 200.0 240.0 280.0
 7--MIDFLAME WINDSPEED, MI/H     9.0
 8--PERCENT SLOPE               15.0
 9--DIRECTION OF WIND VECTOR     0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD          0.0  (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL
```

LIVE WOODY MOIS (%)	RATE OF SPREAD (CH/H)	HEAT PER UNIT AREA (BTU/SQ.FT)	FIRELINE INTENSITY (BTU/FT/S)	FLAME LENGTH (FT)	REACTION INTENSITY (BTU/SQFT/M)	EFFECT. WIND (MI/H)
40.	111.	753.	1535.	13.1	3300.	9.1
80.	69.	700.	890.	10.2	3069.	9.1
120.	35.	475.	308.	6.3	2081.	9.1
160.	15.	255.	71.	3.2	1119.	9.1
200.	13.	255.	59.	2.9	1119.	9.1
240.	11.	255.	51.	2.7	1119.	9.1
280.	10.	255.	45.	2.6	1119.	9.1

Exhibit 14.—DIRECT run showing the effect of live fuel moisture on fire behavior predictions.

Fine dead fuel moisture is one of the primary factors controlling fire behavior at the flaming front. The spread model reflects this fact in the weight it puts on the moisture content of 1-h class compared to 10-h and 100-h. Exhibit 15 shows an example of the relative effect of 1-h and 10-h moistures on rate of spread and flame length predictions. When 10-h is set at 4 percent and 1-h varies from 2 to 14 percent (second column), the resulting rate of spread varies from 51 to 14 ch/h. On the other hand, when 1-h moisture is set at 4 percent and 10-h moisture varies from 2 to 14 percent (second row), rate of spread is always 41 ch/h. Notice also that when the 1-h fuel is wetter, 14 percent, the 10-h fuel moisture has a greater effect on the results.

However, because the fire model is not very sensitive to the moisture contents of 10-h and 100-h fuel, do not conclude that 1-h fuel is the only important component of a fuel model. Figure 6 is a graph from the TSTMDL program of the BEHAVE system (Burgan and Rothermel 1984) showing predicted rate of spread for a range of 10-h fuel loads. This illustrates that when moisture contents are set, the predicted rate of spread can vary significantly, depending on the 10-h fuel load that is present in the fuel model. The conditions for figure 6 correspond to those in exhibit 15. One-hour and 10-h moisture contents are 4 percent; fuel model 2 has 1 ton/acre of 10-h fuels. Therefore, the boxed rate of spread in exhibit 15 (41 ch/h) corresponds to the circled point on the graph in figure 6. (The FIRE1 program gives spread rate in chains per hour while the TSTMDL program uses feet per minute.)

```
1--FUEL MODEL                      2 -- TIMBER (GRASS AND UNDERSTORY)
2--1-HR FUEL MOISTURE, %         2.0    4.0    6.0    8.0   10.0   12.0   14.0
3--10-HR FUEL MOISTURE, %        2.0    4.0    6.0    8.0   10.0   12.0   14.0
4--100-HR FUEL MOISTURE, %       6.0
5--LIVE HERBACEOUS MOIS, %     100.0
7--MIDFLAME WINDSPEED, MI/H      5.0
8--PERCENT SLOPE                15.0
9--DIRECTION OF WIND VECTOR      0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD          0.0  (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL
```

RATE OF SPREAD, CH/HR

1-HR MOIS (%)	10-HR MOIS, % 2.	4.	6.	8.	10.	12.	14.
2.	51.	51.	50.	50.	50.	50.	49.
4.	41.	41.	41.	41.	41.	41.	41
6.	37.	37.	37.	37.	36.	36.	36.
8.	34.	34.	34.	34.	34.	33.	33.
10.	31.	30.	30.	30.	30.	30.	30.
12.	24.	24.	24.	24.	23.	23.	23.
14.	14.	14.	14.	13.	13.	12.	7.

FLAME LENGTH, FT

1-HR MOIS (%)	10-HR MOIS, % 2.	4.	6.	8.	10.	12.	14.
2.	8.2	8.2	8.2	8.1	8.1	8.1	8.1
4.	7.0	7.0	7.0	7.0	6.9	6.9	6.9
6.	6.4	6.4	6.4	6.4	6.4	6.4	6.3
8.	6.1	6.1	6.1	6.0	6.0	6.0	6.0
10.	5.6	5.6	5.6	5.5	5.5	5.5	5.5
12.	4.7	4.6	4.6	4.5	4.5	4.5	4.4
14.	2.9	2.8	2.8	2.7	2.6	2.4	1.5

Exhibit 15.—DIRECT run showing the relative effect of 1-h and 10-h fuel moisture on fire behavior predictions.

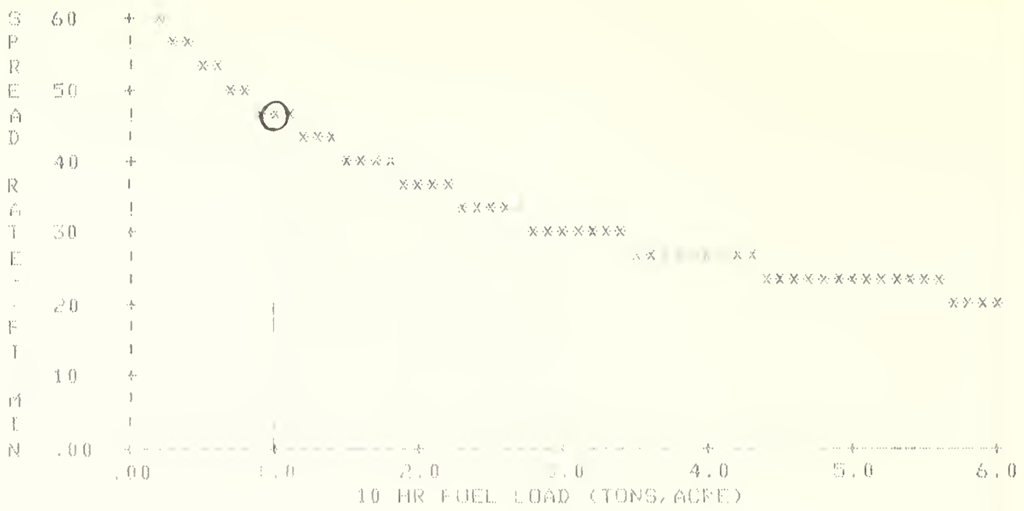

Figure 6.—Graph from TSTMDL showing the effect of a change in 10-h fuel load on spread rate predictions when fuel moisture is held constant.

FINE DEAD FUEL MOISTURE MODEL

Because 1-h moisture content is so important in the spread calculations, a lot of effort has gone into mathematical prediction models. Tables for 1-h fuel moisture have been developed for use by Fire Behavior Officers (FBO) and are described by Rothermel (1983). These tables are well suited for field use and work quite well under the hot, dry conditions typical of escaped wildfire. But BEHAVE will be used for many applications beyond FBO type predictions. Therefore a new model has been developed (Rothermel and others in press) to predict the moisture of fine dead fuel with greater accuracy over a larger range of conditions and times than possible with the FBO procedures. The model is based on the Canadian fine fuel moisture code (FFMC), with changes to allow for drying of surface fuels by solar radiation, initialization methods without a complete record of weather data prior to the startup time, and methods for estimating fine fuel moisture at any time of the day or night.

The Canadian FFMC was developed for shaded conditions. The FBO system is patterned after the NFDRS system, which was designed for worst-case exposed conditions. Rothermel and others (in press) present validation showing that the new moisture model in BEHAVE preserves the capabilities of the Canadian FFMC in shaded conditions and improves it significantly in sunny conditions. Similarly, the BEHAVE moisture model is shown to be at least as good as the FBO methods in dry, sunny conditions and superior in the shade. Test data were available from Idaho, Texas, Arizona, and Alaska.

Some important aspects that affect fuel moisture are not in this model but will likely be considered in future revisions. The most significant of these are the effects of moisture in the duff and soil beneath the litter layer and the effects of cooling due to nighttime radiation losses and dew formation. Other considerations omitted at this time are differences in moisture because fuels are either standing (such as grass) or lying on the ground, differences between freshly fallen and old litter, and differences caused by fuel coating, such as bark or wax.

The label "1-hour timelag" is applied to dead fuel, 0 to one-quarter inch in diameter. Byram (1963) demonstrated that the moisture content of dead fuels drying under constant conditions follows an exponential decay curve. He defined the timelag interval as the time required for fuels to lose approximately

two-thirds (actual value is 1/e where e = base of natural logarithms) of their initial moisture content. Because conditions are never constant, fuel moisture is continually seeking an equilibrium value which is based on the current temperature and relative humidity. Van Wagner (1974) showed that an estimate of the moisture content of fine fuels should consider the fuel moisture content on the previous day. Therefore the new moisture model requires much more information than the weather conditions at the time of the estimation.

For the purposes of the moisture model used in SITE, a "burn day" goes from 1200 to 1200 as shown in figure 7. Burn day −1 ("burn day minus one") is the previous 24-hour period from 1200 to 1200. Burn day is set up this way because of the input requirements for diurnal adjustments as described later. All times are solar time. In most cases, local standard time can be used.

Figure 7.—"Burn day" goes from 1200 to 1200.

The major sections of the model include correction of temperature and humidity for the elevation difference between the site of the weather readings and fire site, correction of temperature and humidity for solar heating, initialization of the moisture content, calculation of early afternoon moisture, and diurnal adjustment of fuel moisture (fig. 8). Figures 9 and 10 show the flow of the fine fuel moisture model along with the SITE input values that are utilized at each step.

It is often necessary to use temperature and humidity readings that are not taken at the site where the fuel moisture value is needed. For a well-mixed atmosphere (no inversion), the adiabatic lapse rate is used to adjust temperature and humidity according to elevation differences. If the elevation difference is less than 1,000 ft, no correction is applied.

One of the primary features of the model is a correction for solar heating used to adjust the temperature and humidity measured at standard weather shelter height to the conditions at fuel level. The input values that determine solar heating are date, latitude, slope, elevation, aspect, canopy cover, cloud cover, haziness, and windspeed.

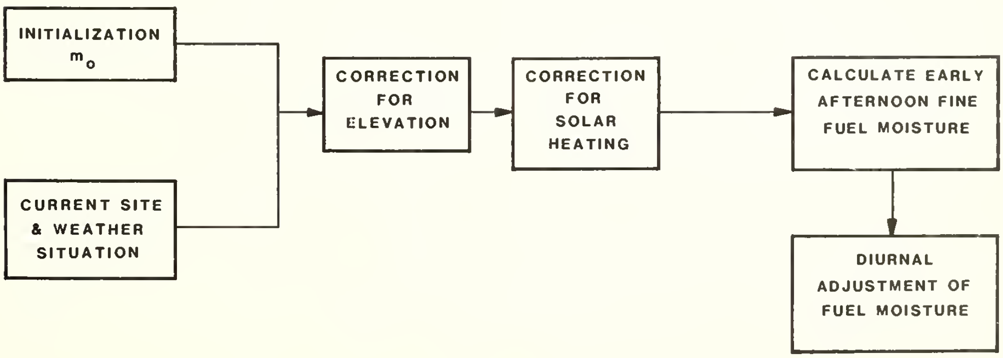

Figure 8.—General flow diagram of the fine fuel moisture model (from Rothermel and others in press).

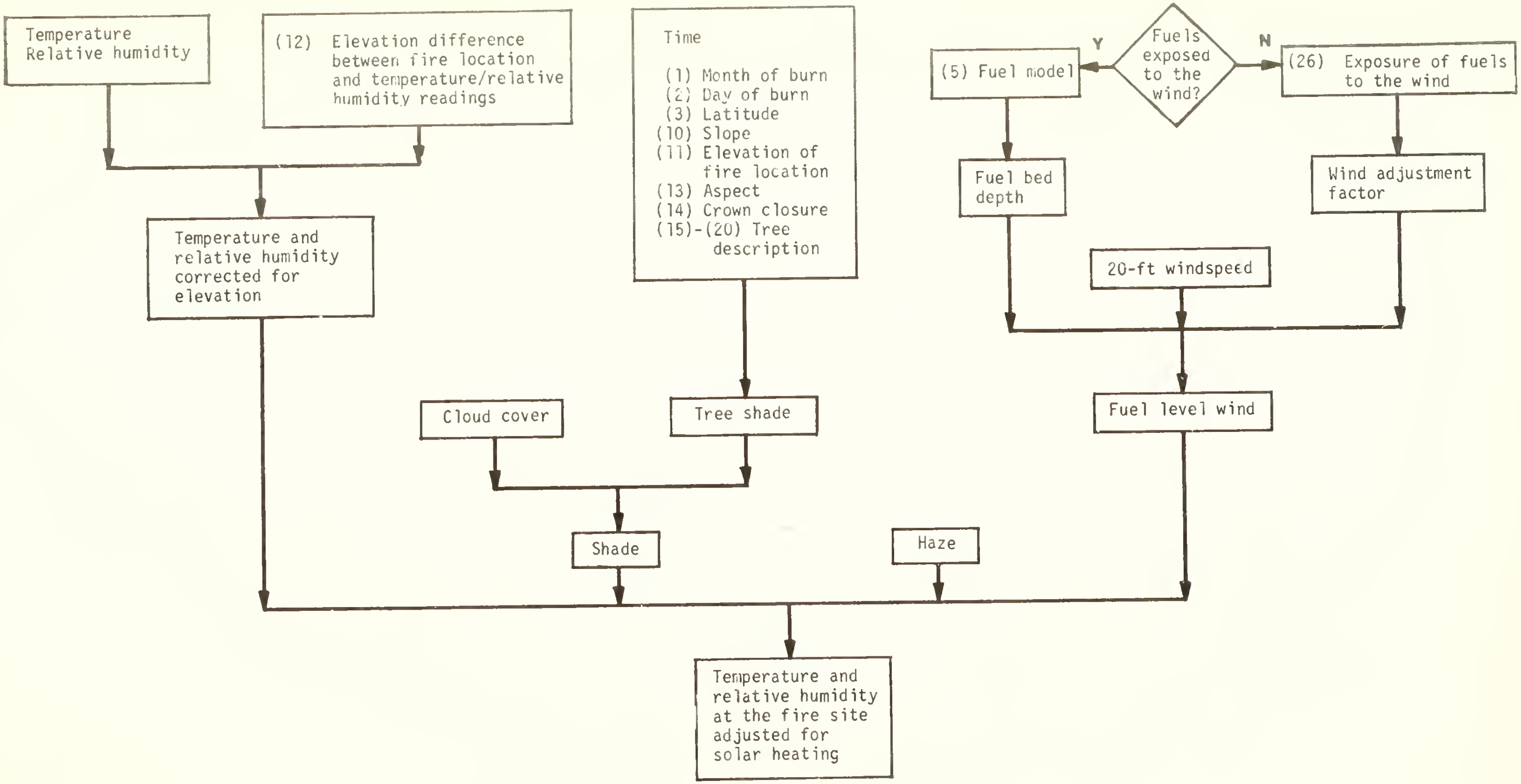

Figure 9.—Flow diagram of the part of the fine fuel moisture model that adjusts temperature and relative humidity for elevation and solar heating. This adjustment is used several places in the model. SITE input values and line numbers are shown at each step.

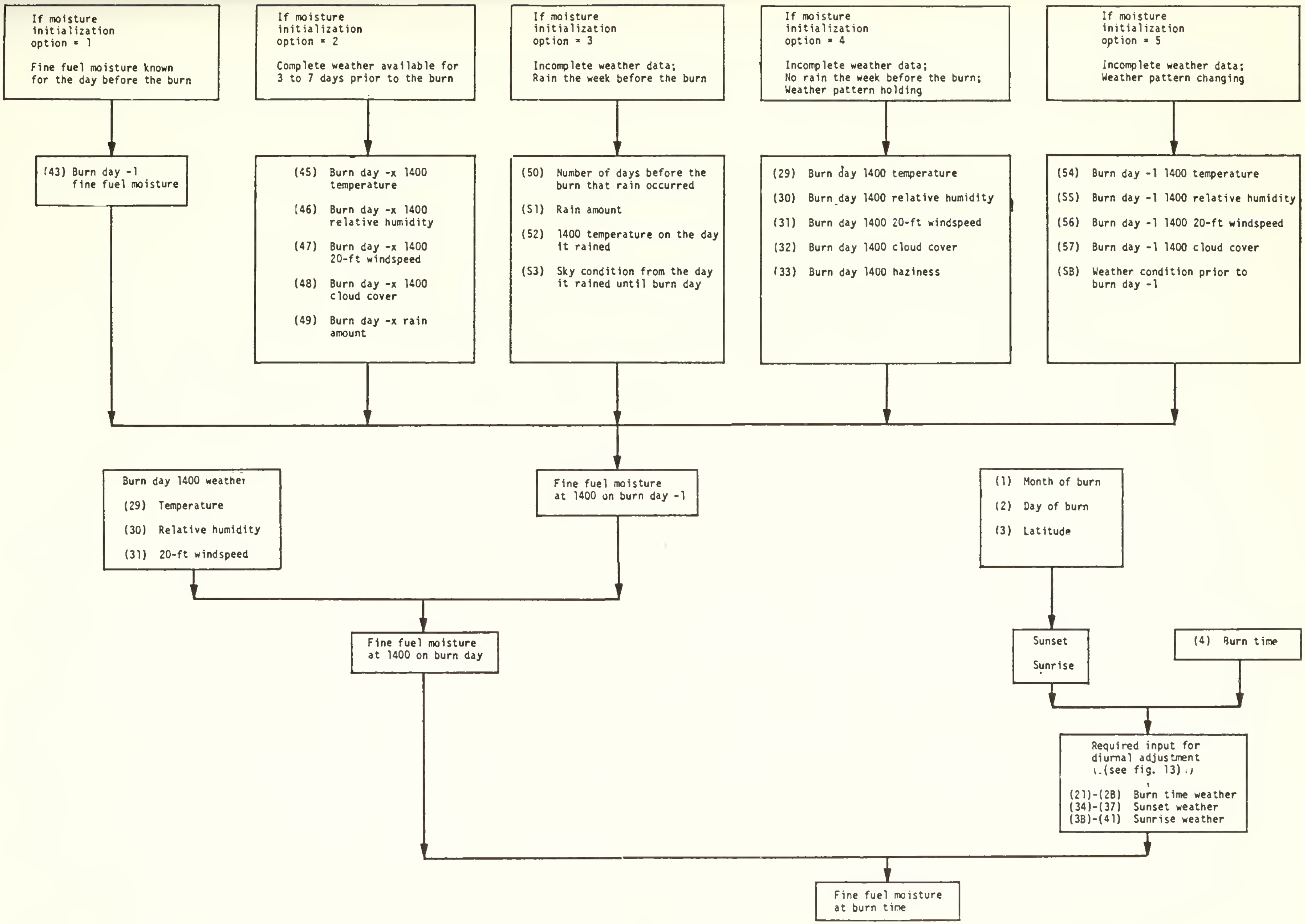

Figure 10.—Flow diagram of the fine fuel moisture model showing moisture initialization, calculation of 1400 moisture on burn day, and diurnal adjustment of fuel moisture. SITE input values and line numbers are shown at each step.

Canopy cover is described in terms of crown closure, presence or absence of foliage, shade tolerance, tree type (coniferous or deciduous), average tree height, ratio of crown length to tree height, and ratio of crown length to crown diameter. Aids to estimating crown closure and crown ratios are given in figures 11 and 12. In addition, SITE facilitates the estimation of latitude by converting a two-letter State abbreviation to an average latitude as shown in exhibit 16.

Windspeed is used in adjusting temperature and humidity for solar heating because turbulent mixing cools fuel being heated by the sun. When fuels are exposed to the wind, an equation developed by Albini and Baughman (1979) is

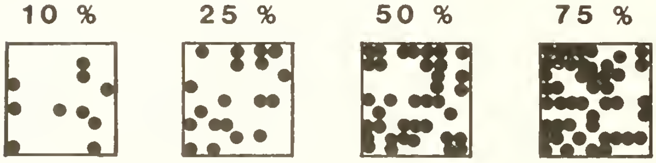

Figure 11.—Aid to estimating canopy closure, an input to SITE.

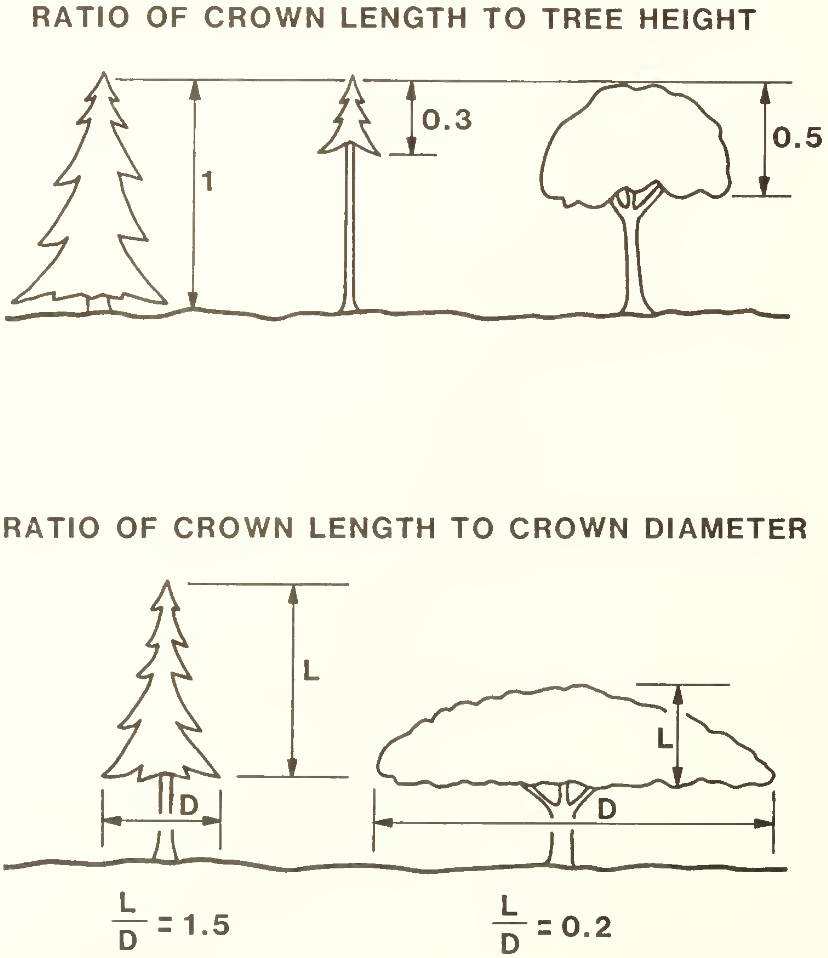

Figure 12.—Aid to estimating ratio of crown length to tree height and ratio of crown length to crown diameter, input values to SITE.

State	Abbreviation	Latitude	State	Abbreviation	Latitude
Alabama	AL	33	Montana	MT	46
Alaska	AK	65	Nebraska	NE	42
Arizona	AZ	35	Nevada	NV	40
Arkansas	AR	35	New Hampshire	NH	44
California	CA	38	New Jersey	NJ	40
Colorado	CO	40	New Mexico	NM	35
Connecticut	CT	41	New York	NY	44
Delaware	DE	44	North Carolina	NC	36
Florida	FL	25	North Dakota	ND	46
Georgia	GA	33	Ohio	OH	40
Hawaii	HI	20	Oklahoma	OK	35
Idaho	ID	45	Oregon	OR	43
Illinois	IL	40	Pennsylvania	PA	40
Indiana	IN	40	Rhode Island	RI	41
Iowa	IA	42	South Carolina	SC	34
Kansas	KS	39	South Dakota	SD	44
Kentucky	KY	39	Tennessee	TN	36
Louisiana	LA	32	Texas	TX	35
Maine	ME	46	Utah	UT	40
Maryland	MD	39	Vermont	VT	44
Massachusetts	MA	42	Virginia	VA	38
Michigan	MI	44	Washington	WA	46
Minnesota	MN	46	West Virginia	WV	38
Mississippi	MS	32	Wisconsin	WI	44
Missouri	MO	39	Wyoming	WY	43

Exhibit 16.—Two-letter State abbreviations and the latitude that is assigned by SITE.

used to estimate fuel-level windspeed from the 20-ft windspeed. When fuels are sheltered from the wind, the wind-adjustment factor is used to find the fuel level wind.

The adjustments to temperature and relative humidity described above and shown in figure 9 are used in several places in the model. Figure 10 shows the moisture initialization, calculation of the 1400 moisture, and diurnal adjustment of the moisture content. These sections of the model are described below.

Initialization sets the fuel moisture at 1400 on the day before the burn (burn day −1). Choice of one of the initialization options depends on the information that is available; option 1 requires that the initial fine fuel moisture be input directly. This value might be obtained by measurement of a fuel sample. Option 2 calculates the initial moisture from complete weather records for 3 to 7 days prior to the day of the burn (temperature, humidity, windspeed, cloud cover, and rain amount). If complete weather data are not available, options 3, 4, or 5 can be used. Option 3 is used when there is rain the week prior to the burn. Because of calculations about the air mass, this option can be used only if there has been no frontal passage since the rain. Input consists of days since rain, amount of rain, early afternoon temperature on the day it rained, and sky condition between the day of rain and burn day (clear, cloudy, or partly cloudy). Option 4 is used when it did not rain the week prior to the burn and weather conditions are persistent from day to day. No additional input is required for this option. The burn day weather is used to estimate the initial moisture value. Option 5 is used when it does not rain the week prior to the burn and weather conditions are variable. Input consists of an estimate of the early afternoon weather conditions for the day prior to the burn (temperature, humidity,

windspeed, and cloud cover), and the general weather pattern prior to that: (1) hot and dry, (2) cool and wet, or (3) between 1 and 2.

The early afternoon (1400) moisture content is calculated from the initial fuel moisture described above and the temperature, humidity, and windspeed on burn day. The calculations utilize the Canadian FFMC.

In order to determine the moisture content at any other time of day or night, additional input is required as shown in figure 13. Temperature and relative humidity values at each hour are predicted from sinusoidal curves linking the 1400 weather to the burn time weather as shown in figure 14.

The fine fuel moisture model is now part of the SITE module. There are plans to add a new module (MOISTURE) to the next update of BEHAVE, consisting only of the moisture model without the spread and intensity predictions. Options for table or graphic output will be offered.

There are 58 items on the SITE worksheet. Most of these are for the moisture model. Because there are options on the required input, depending on the information that is available, it is never necessary to input all 58 values. In fact SITE can be run with as few as 15 values specified as shown in the run in appendix A. The worksheet for SITE shows the conditions that require each input value. A line-by-line description of each input variable is in appendix B.

Burn time between	1200 and 1600	1600 and sunset		sunset and sunrise			sunrise and 1200			
Conditions required for	1400 = BT*	1400	BT	1400	SS	BT	1400	SS	SR	BT
Temperature	x	x	x	x	x	x	x	x	x	x
Relative humidity	x	x	x	x	x	x	x	x	x	x
Windspeed	x	x	x	x	x	x	x	x	x	x
Cloud cover	x	x	x	x	x		x	x	x	x
Haziness	x	x		x			x			x

BT = burn time

SS = sunset

SR = sunrise

*Conditions are assumed to be constant from 1200 to 1600.

Figure 13.—Chart indicating weather parameters needed according to the specified burn time.

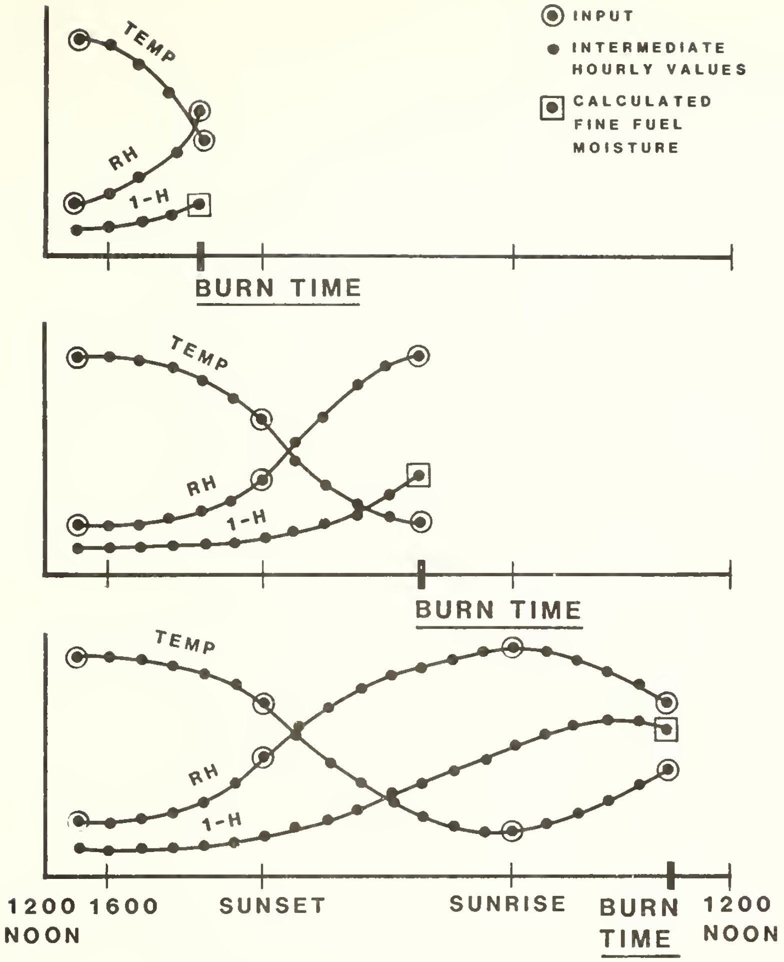

Figure 14.—Temperature and relative humidity at each hour are predicted from sinusoidal curves linking input values. These hourly values are used in calculating fine fuel moisture.

Windspeed

In "How to Predict the Spread and Intensity of Forest and Range Fires," Rothermel (1983) discusses "procedures for obtaining the necessary wind information from weather forecasts and for interpreting measurements made at the fire site to produce the required windspeed input to the fire model." Rothermel's publication describes real-time fire behavior prediction from a Fire Behavior Officer's point of view. The situation is simplified if you are using fire behavior prediction to answer "what if" planning questions. In any case you should study the wind section in Rothermel (1983) so that you will fully understand what is behind the question: MIDFLAME WINDSPEED, MI/H?

The windspeed input to the fire model is the speed of the wind without influence of the fire. The effects of indrafts on a steadily spreading fire are built into the model. Therefore you do not have to consider the fire's influence upon the wind. However, the model does not handle the interactions between two fire fronts or the effect of drafts caused by a "mass" fire. This emphasizes the fact that you should not use the predictions in fire situations for which the fire model was not designed, such as prescribed fires, where the method and pattern of ignition are used to control fire behavior.

In the United States, land management agencies measure wind at a standard height of 20 ft above the ground, adjusted for depth of vegetation (Fischer and Hardy 1976). The windspeed required by the fire model is at a height above the surface fuel that would be equivalent to the midlevel height of flames from the expected fire, namely midflame windspeed. Midflame windspeed can be calculated from 20-ft windspeed and a wind adjustment factor based on fuel model, topography, and canopy cover (table 3) (Albini and Baughman 1979).

Table 3.—Wind adjustment table. The appropriate adjustment factor is multiplied by the 20-ft windspeed to obtain midflame windspeed

Shelter	Fuel model	Adjustment factor
Exposed Fuels		
Fuel exposed directly to the wind—no overstory or sparse overstory;	4	0.6
fuel beneath timber that has lost its foliage; fuel beneath timber	13	.5
near clearings or clearcuts; fuel on high ridges where trees offer little shelter from wind	1,3,5,6,11,12 (2,7)[1] (8,9,10)[2]	.4
Partially Sheltered Fuels		
Fuels beneath patchy timber where it is not well sheltered; fuel beneath standing timber at midslope or higher on a mountain with wind blowing directly at the slope	All	.3
Fully Sheltered Fuels		
Fuel sheltered beneath standing timber on flat or gentle slope or near base of mountain with steep slopes	All — Open stands	.2
	All — Dense stands	.1

[1]These fuels are usually partially sheltered.
[2]These fuels are usually fully sheltered.

DIRECT requires direct input of midflame windspeed. DISPATCH asks for the 20-ft windspeed and the wind adjustment factor. SITE asks for 20-ft windspeed. If you know the degree of exposure of fuels to the wind, it can be entered directly, otherwise SITE will help you determine it. The information that SITE uses in determining the wind adjustment factor is diagrammed in figure 15.

The adjustment factor for exposed fuels depends on the fuel model, but the adjustment factors for sheltered and partially sheltered fuels do not. The fuel models included in table 3 are the 13 NFFL models. Adjustment factors for custom fuel models are calculated as described by Rothermel (1983, p. 138) and stored in the fuel model file. They are printed with the parameters when you use the keyword CUSTOM (exhibit 10). You may want to add the factors for your favorite custom models to table 3 for future reference.

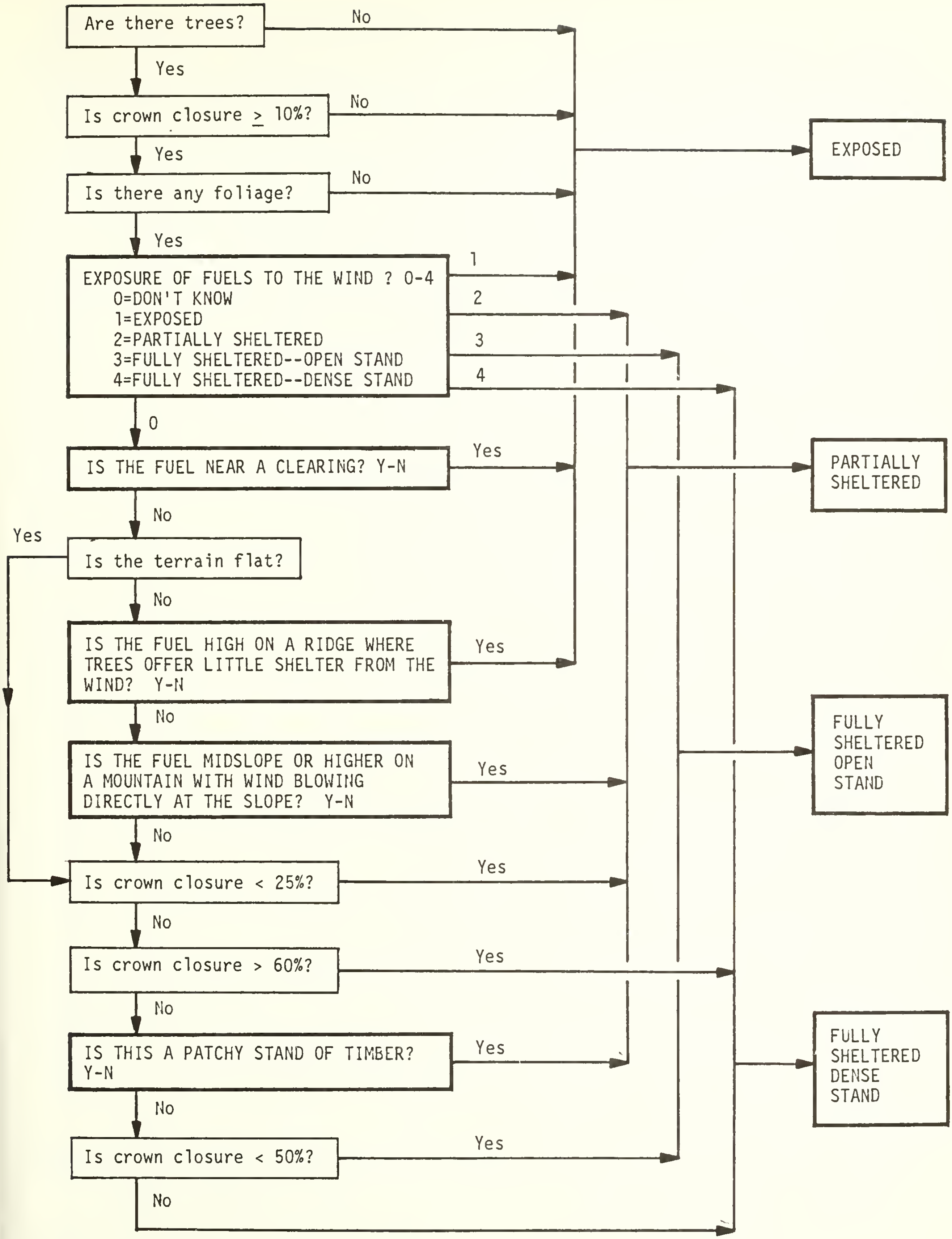

Figure 15.—Information that is used in SITE to determine wind adjustment factor. Questions printed in capital letters are asked directly of the user. Others are based on information entered previously.

Slope

Rothermel (1983) discusses the effect of slope on fire behavior, the relative effect of wind and slope, and how to deal with rough terrain. The slope value used by the spread model is the maximum percent slope of the terrain immediately above the fire. Predictions for cross-slope fire spread are accomplished by specifying the relative directions of slope, wind, and spread as described in a previous section.

DIRECT requires direct entry of percent slope. SITE allows you to enter measurements from a topographic map to calculate percent slope as described by Rothermel (1983). An example is given in exhibit 17. You are asked to describe the map that you are using in terms of the map scale and the contour interval. The map scale can be specified either as a representative fraction or as inches per mile. You can specify one of eight common map scales by entering a single digit or you can enter a value for the map scale directly. For the specific area for which you want to determine percent slope, you enter a distance in inches and the number of contour intervals over that distance.

```
(10) DO YOU WANT TO ENTER MAP MEASUREMENTS TO
     CALCULATE PERCENT SLOPE ? Y-N
>Y

(10) MAP SCALE ? 0-8
       0=DIRECT ENTRY      1-8=CODE

           REP.FRAC.  IN/MI         REP.FRAC.  IN/MI
       1=  1:253,440   1/4      5=  1:24,000    2.64
       2=  1:126,720   1/2      6=  1:21,120    3
       3=  1:63,360    1        7=  1:15,840    4
       4=  1:31,680    2        8=  1:7,920     8
>5

(10) CONTOUR INTERVAL, FT ? 10-500
>20

(10) MAP DISTANCE  INCHES ? .1-10
>.4

(10) NUMBER OF CONTOUR INTERVALS ? 1-100
>15


MAP SCALE = 1: 24000. = 2.64 IN/MI =  2000. FT/IN
RISE IN ELEVATION   =  300. FT
HORIZONTAL DISTANCE =  800. FT

SLOPE = 37.%
```

Exhibit 17.—Example of the slope determination aid in SITE.

Area and Perimeter (SIZE)

The shape of a fire that starts from a point source, such as lightning or a firebrand, is roughly elliptical. Anderson (1983) has developed double ellipse equations to describe the shape. The equations used in FIRE1 are for a simple ellipse (Andrews and Morris in preparation). This simplification was necessary so that the assumptions of the containment model would be met and so that there would be consistency with the direction equations. This also allows calculations of area and perimeter when winds are blowing across the slope.

Area and perimeter of a point-source fire can be calculated from forward rate of spread, effective windspeed, and elapsed time from ignition. Conditions are assumed to be relatively constant over the projection period. The fire is assumed to be spreading steadily in surface fuels during the lapsed time. This does not include the time that an ignition may smolder before it begins to spread. Rate of spread and elapsed time give the forward spread distance. Effective windspeed determines the shape of the fire.

Rate of spread and effective windspeed are calculated by DIRECT and SITE. These values can be used along with the additional input of time in the SIZE calculations. An example of SIZE linked to DIRECT is shown in exhibit 18A. The fire shapes that correspond to these calculations are given in figure 16A.

It is also possible to use SIZE as an independent module. In this case rate of spread, effective windspeed, and elapsed time are entered directly as input. An example of an independent run of SIZE is given in exhibit 18B. The corresponding fire shapes are in figure 16B. This illustrates the effect of effective windspeed on fire shape, because all of these fires have the same forward rate of spread. The fires are narrower under higher windspeeds. Notice also that backing spread distance decreases with increasing windspeed.

A.

```
 1--FUEL MODEL                       9 -- HARDWOOD LITTER
 2--1-HR FUEL MOISTURE, %            4.0
 3--10-HR FUEL MOISTURE, %           5.0
 4--100-HR FUEL MOISTURE, %          5.0
 7--MIDFLAME WINDSPEED, MI/H         4.0    6.0    8.0
 8--PERCENT SLOPE                    0.0
 9--DIRECTION OF WIND VECTOR         0.0
10--DIRECTION OF SPREAD              0.0   (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM THE WIND VECTOR
```

MIDFLAME WIND (MI/H)	RATE OF SPREAD (CH/H)	HEAT PER UNIT AREA (BTU/SQ.FT)	FIRELINE INTENSITY (BTU/FT/S)	FLAME LENGTH (FT)	REACTION INTENSITY (BTU/SQFT/M)	EFFECT. WIND (MI/H)
4.	8.	416.	57.	2.9	2691.	4.0
6.	14.	416.	108.	3.9	2691.	6.0
8.	23.	416.	172.	4.8	2691.	8.0

```
1--RATE OF SPREAD, CH/H        OUTPUT FROM DIRECT, RANGE=   8. TO  23.
2--EFFECTIVE WIND, MI/H        OUTPUT FROM DIRECT, RANGE=  4.0 TO  8.0
3--ELAPSED TIME, HR            1.5
```

MIDFLAME WIND (MI/H)	AREA (AC)	PERIMETER (CH)	LENGTH-TO-WIDTH RATIO	FORWARD SPREAD DISTANCE (CH)	BACKING SPREAD DISTANCE (CH)	MAXIMUM WIDTH OF FIRE (CH)
4.	5.8	29.	2.0	11.3	0.8	6.1
6.	15.3	51.	2.5	21.2	0.9	8.8
8.	31.6	77.	3.0	33.8	1.0	11.6

B.

```
1--RATE OF SPREAD, CH/H        14.0
2--EFFECTIVE WIND, MI/H         4.0    6.0    8.0
3--ELAPSED TIME, HR             1.5
```

EFFECT. WIND (MI/H)	AREA (AC)	PERIMETER (CH)	LENGTH-TO-WIDTH RATIO	FORWARD SPREAD DISTANCE (CH)	BACKING SPREAD DISTANCE (CH)	MAXIMUM WIDTH OF FIRE (CH)
4.	20.	55.	2.0	21.0	1.5	11.3
6.	15.	50.	2.5	21.0	0.9	8.8
8.	12.	48.	3.0	21.0	0.6	7.2

Exhibit 18.— (A)Example of SIZE linked to DIRECT; (B) SIZE run independently.

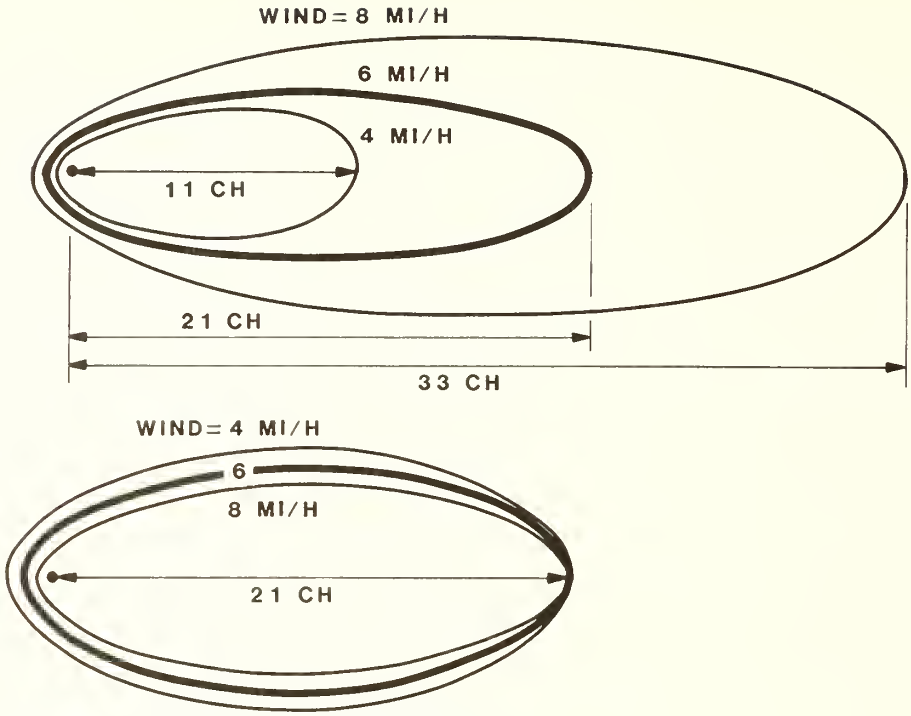

Figure 16.—(A) Fire shapes that correspond to the run in exhibit 18A; (B) fire shapes that correspond to the run in exhibit 18B.

As shown in exhibit 18B, when rate of spread is input as a **constant** value, area and perimeter decrease with an increase in effective windspeed due to the change in fire shape. When SIZE is run independently, effective windspeed does not affect rate of spread; but when SIZE is linked to either DIRECT or SITE, effective windspeed is used in the rate-of-spread calculations. Therefore, in exhibit 18A area and perimeter increase with increasing windspeed. Notice in the DIRECT run in exhibit 18A that the calculated rate of spread for a midflame windspeed of 6 mi/h is 14 ch/h. Because the slope is zero, midflame windspeed is equal to effective windspeed. The constant rate of spread for exhibit 18B was also 14 ch/h. Therefore, the calculated area and perimeter for these cases is the same, 15 acres. (When any of the values for area in a table is less than 10 acres, area is printed to the nearest 0.1 acre, otherwise it is rounded to the nearest acre.)

Refer to exhibit 2 to review the two places in the FIRE1 keyword hierarchy where SIZE can be entered as a keyword. The usual way to use SIZE is to link it to DIRECT or SITE. But you can use SIZE independently when you want to calculate specific rate of spread and effective windspeed conditions or if you want to examine the area and perimeter model itself.

Fire Containment (CONTAIN)

The CONTAIN module is used to estimate requirements for fire suppression activities. CONTAIN predicts final fire size, given forward rate of spread, initial fire size, fire shape length-to-width ratio, and control-line construction rate. It can also be used to find the line construction rate needed to hold the burned area to a fixed value (Albini and Chase 1980; Albini and others 1978). The containment model in BEHAVE is different from the more generalized simulation model used in the Forest Service Fire Planning and Analysis process (FSH 5109.19).

In order to formulate the containment problem as a mathematical model, some basic limiting assumptions were made:

1. The fire has an elliptical shape at the time of attack.
2. Conditions are constant over the time that fireline is being constructed.
3. The containment line is constructed at the edge of the fire.
4. The fire is attacked either at the head or the rear. Work then proceeds simultaneously on both sides of the fire at an equal pace.

Application of the containment model should be limited to situations that reasonably match the above conditions; that is, initial attack on spot fires that can be contained in one burning period. Because fires are usually attacked directly (fireline is constructed within a few feet of the fire), the model cannot be applied to high-intensity fires. Major application of predictions from CONTAIN include contingency planning, initial attack dispatching, and preliminary fire control planning.

Predictions can be made for either head or rear attack. Exhibit 19 shows the calculated final fire size under a range of line building rates for the

```
1---RUN OPTION                          2. COMPUTE BURNED AREA
2---MODE OF ATTACK                      1. HEAD
3---RATE OF SPREAD, CH/H               10.0
4---INITIAL FIRE SIZE, ACRES           10.0
5---LENGTH-TO-WIDTH RATIO               2.0
7---LINE BUILDING RATE, CH/H           20.0   30.0   40.0   50.0

  LINE     I   TOTAL      CONTAINMENT      FINAL
BUILDING   I   LENGTH        TIME          FIRE
  RATE     I   OF LINE     (HOURS)         SIZE
 (CH/H)    I    (CH)                      (ACRES)
           I
           I
  20.      I     -2.        -2.0            -2.
           I
  30.      I     48.         1.6            17.
           I
  40.      I     45.         1.1            15.
           I
  50.      I     43.         0.9            14.

    -2 = FORWARD RATE OF SPREAD IS EITHER GREATER THAN
         OR NEARLY EQUAL TO LINE BUILDING RATE PER FLANK.

1---RUN OPTION                          2. COMPUTE BURNED AREA
2---MODE OF ATTACK                      2. REAR
3---RATE OF SPREAD, CH/H               10.0
4---INITIAL FIRE SIZE, ACRES           10.0
5---LENGTH-TO-WIDTH RATIO               2.0
7---LINE BUILDING RATE, CH/H           20.0   30.0   40.0   50.0

  LINE     I   TOTAL      CONTAINMENT      FINAL
BUILDING   I   LENGTH        TIME          FIRE
  RATE     I   OF LINE     (HOURS)         SIZE
 (CH/H)    I    (CH)                      (ACRES)
           I
           I
  20.      I     -2.        -2.0            -2.
           I
  30.      I    120.         4.0            67.
           I
  40.      I     79.         2.0            34.
           I
  50.      I     65.         1.3            25.

    -2 = FORWARD RATE OF SPREAD IS EITHER GREATER THAN
         OR NEARLY EQUAL TO LINE BUILDING RATE PER FLANK.
```

Exhibit 19.—Example independent CONTAIN runs for head and rear attack.

two modes of attack, head and rear. Figure 17 illustrates initial and final fire shapes. These diagrams correspond to the CONTAIN runs in exhibit 19 for line-building rate of 40 ch/h. The only difference between the two examples is the point of initial attack.

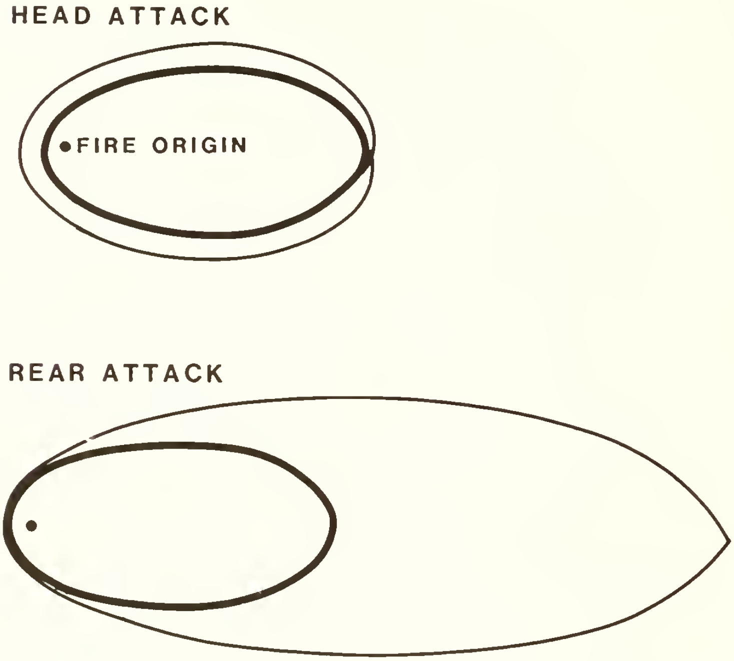

Figure 17.—Initial and final fire shapes corresponding to CONTAIN predictions in exhibit 19.

In order to calculate the final fire size, the line-building rate must be specified (as in exhibit 19). Guidelines for line-building rate are not programmed into BEHAVE. Line construction rates for NFDRS fuel models are published in Fire Management Analysis and Planning Handbook (FSH 5109.19). Similar tables utilizing the 13 NFFL fuel models have been prepared by Schmidt and Rinehart (1982). Phillips and Barney (1984) have published bulldozer production rates for various dozer sizes, fuels, and slopes. Haven and others (1982) compared studies of crews using handtools to build firelines, finding wide variation in construction rates. They reported that rates at which hand crews construct firelines can vary widely because of differences in fuels, fire and measurement conditions, and fuel resistance-to-control classification schemes. Barney (1983) presented a conceptual model of fireline production in an attempt to overcome problems found in earlier production data. But until more definitive guidelines are available for line-building rates, it is up to you as a BEHAVE user to supply an appropriate value based on experience and local guidelines.

CONTAIN uses total line-building rate, as opposed to line-building rate **per flank** as used in the TI-59 program. Therefore, within BEHAVE, the line-building rate is divided in half and applied to each flank of the fire. The line-building rate **per flank** must be greater than the forward rate of spread of the fire (see exhibit 19). Otherwise the control forces will never catch the fire whether it is attacked at the head or the rear. And understandably the target fire size must be larger than the initial fire size.

CONTAIN can be used independently, as it is with the TI-59 program (Albini and Chase 1980). The examples in exhibit 19 are independent runs of CONTAIN. Alternatively, CONTAIN can be linked to SIZE and either DIRECT or SITE as shown in exhibit 20. When CONTAIN is linked to other modules, some of the input values are calculated rather than input directly as they are when CONTAIN is used independently. Rate of spread comes from DIRECT or SITE and initial fire size and length-to-width ratio come from SIZE. In addition, fireline intensity from DIRECT or SITE is available for each containment calculation. Recall that this value is related to suppression capabilities (table 1). The containment calculations are done as usual, but footnotes indicate when the fire may be too intense for direct attack. In exhibit 20, part 1, flame lengths of 4 to 8 ft have been indicated on the table. The containment values (exhibit 20, part 3) that correspond to these locations on the table are designated by an *.

At first glance, you may question the fact that containment time increases as fuel moisture increases and as wind decreases (exhibit 20, part 3). But remember that we have specified a burned area target of 10 acres. The fire will be contained when it reaches 10 acres, not before. It takes fewer resources, that is a lower line-building rate (exhibit 20, part 3), to contain a slowly spreading fire (exhibit 20, part 1) at 10 acres than it would to contain a fast-spreading fire at 10 acres.

Notice that the total length of line (exhibit 20, part 3) is constant for low windspeeds under the entire range of 1-h moisture values (see the first three columns). This is because the initial fire size (exhibit 20, part 2) is almost constant and is very small compared to the burned area target of 10 acres.

Part 1. DIRECT.

```
 1--FUEL MODEL                     10 -- TIMBER (LITTER AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %           2.0    4.0    6.0    8.0   10.0   12.0   14.0
 3--10-HR FUEL MOISTURE, %          8.0
 4--100-HR FUEL MOISTURE, %        12.0
 6--LIVE WOODY MOISTURE, %         50.0
 7--MIDFLAME WINDSPEED, MI/H        0.0    1.0    2.0    3.0    4.0    5.0    6.0
 8--PERCENT SLOPE                   6.0
 9--DIRECTION OF WIND VECTOR        0.0
      DEGREES CLOCKWISE
       FROM UPHILL
10--DIRECTION OF SPREAD             0.0  (DIRECTION OF MAX SPREAD)
    CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL
```

RATE OF SPREAD, CH/HR

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
2.	2.	3.	5.	8.	12.	16.	20.
4.	1.	3.	5.	7.	11.	14.	18.
6.	1.	2.	4.	7.	10.	13.	16.
8.	1.	2.	4.	6.	9.	12.	15.
10.	1.	2.	4.	6.	8.	11.	14.
12.	1.	2.	4.	6.	8.	10.	13.
14.	1.	2.	3.	5.	7.	10.	13.

FLAME LENGTH, FT

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
2.	2.6	3.5	4.6	5.7	6.7	7.6	8.5
4.	2.4	3.2	4.2	5.2	6.1	6.9	7.7
6.	2.2	3.0	3.9	4.8	5.6	6.4	7.1
8.	2.1	2.8	3.7	4.5	5.3	6.0	6.7
10.	2.0	2.7	3.5	4.3	5.1	5.8	6.5
12.	1.9	2.6	3.4	4.2	4.9	5.6	6.2
14.	1.8	2.5	3.3	4.0	4.7	5.4	6.0

Exhibit 20.—Example CONTAIN run linked to DIRECT and SIZE.

```
1--RATE OF SPREAD, CH/H        OUTPUT FROM DIRECT. RANGE=    1. TO   20.
2--EFFECTIVE WIND, MI/H        OUTPUT FROM DIRECT. RANGE=  0.1 TO   6.0
3--ELAPSED TIME, HR            0.5
```

AREA, ACRES

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
2.	0.1	0.2	0.5	1.0	1.6	2.4	3.4
4.	0.1	0.2	0.4	0.7	1.3	1.9	2.7
6.	0.1	0.1	0.3	0.6	1.0	1.6	2.2
8.	0.1	0.1	0.3	0.5	0.9	1.3	1.9
10.	0.1	0.1	0.2	0.5	0.8	1.2	1.7
12.	0.1	0.1	0.2	0.4	0.7	1.1	1.5
14.	0.0	0.1	0.2	0.4	0.6	1.0	1.4

PERIMETER, CHAINS

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
2.	4.	5.	8.	12.	15.	20.	24.
4.	3.	5.	7.	10.	14.	17.	21.
6.	3.	4.	7.	9.	12.	16.	19.
8.	3.	4.	6.	9.	11.	15.	18.
10.	3.	4.	6.	8.	11.	14.	17.
12.	3.	3.	5.	8.	10.	13.	16.
14.	2.	3.	5.	7.	10.	12.	15.

Exhibit 20. (Con.)

```
1--RUN OPTION                      1. COMPUTE LINE BUILDING RATE
2--MODE OF ATTACK                  1. HEAD
3--RATE OF SPREAD, CH/H            OUTPUT FROM DIRECT. RANGE=     1. TO    20.
4--INITIAL FIRE SIZE, ACRES        OUTPUT FROM SIZE.   RANGE=     0. TO     3.
5--LENGTH-TO-WIDTH RATIO           OUTPUT FROM SIZE.   RANGE=   1.0 TO    2.5
6--BURNED AREA TARGET, AC         10.0
```

TOTAL LENGTH OF LINE, CHAINS

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
2.	38.	43.	46.*	48.*	49.*	49.*	47.#
4.	38.	43.	46.*	49.*	50.*	51.*	51.*
6.	38.	43.	46.*	49.*	51.*	52.*	53.*
8.	38.	43.	46.	49.*	51.*	53.*	54.*
10.	38.	43.	46.	49.*	51.*	53.*	55.*
12.	38.	43.	46.	49.*	51.*	54.*	55.*
14.	38.	43.	46.	49.*	52.*	54.*	56.*

CONTAINMENT TIME, HOURS

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
2.	11.4	7.1	4.2*	2.8*	2.1*	1.5*	1.2#
4.	13.0	8.1	4.8*	3.3*	2.4*	1.8*	1.4*
6.	14.5	9.0	5.3*	3.6*	2.7*	2.1*	1.6*
8.	15.8	9.7	5.7	3.9*	2.9*	2.3*	1.8*
10.	16.9	10.3	6.1	4.2*	3.1*	2.4*	2.0*
12.	17.9	10.8	6.4	4.4*	3.3*	2.6*	2.1*
14.	19.0	11.5	6.8	4.6*	3.4*	2.7*	2.2*

```
* = FIRE IS TOO INTENSE FOR DIRECT ATTACK BY
      HAND CREWS.
    EQUIPMENT SUCH AS DOZERS, PUMPERS, PLOWS,
      AND RETARDANT AIRCRAFT CAN BE EFFECTIVE.

# = CONTROL EFFORTS AT THE HEAD OF THE FIRE
    WILL PROBABLY BE INEFFECTIVE.
```

Exhibit 20. (Con.)

```
LINE BUILDING RATE, CH/H

  1-HR     I        MIDFLAME WIND, MI/H
  MOIS     I
  (%)      I      0.      1.      2.      3.      4.      5.      6.
           I------------------------------------------------------------
           I
  2.       I      3.      6.     11.*    17.*    24.*    32.*    40.#
           I
  4.       I      3.      5.     10.*    15.*    21.*    28.*    36.*
           I
  6.       I      3.      5.      9.*    14.*    19.*    25.*    32.*
           I
  8.       I      2.      4.      8.     13.*    18.*    24.*    30.*
           I
 10.       I      2.      4.      8.     12.*    17.*    22.*    28.*
           I
 12.       I      2.      4.      7.     11.*    16.*    21.*    27.*
           I
 14.       I      2.      4.      7.     11.*    15.*    20.*    25.*
           I

        * = FIRE IS TOO INTENSE FOR DIRECT ATTACK BY
              HAND CREWS.
            EQUIPMENT SUCH AS DOZERS, PUMPERS, PLOWS,
              AND RETARDANT AIRCRAFT CAN BE EFFECTIVE.

        # = CONTROL EFFORTS AT THE HEAD OF THE FIRE
             WILL PROBABLY BE INEFFECTIVE.
```

Exhibit 20. (Con.)

Maximum Spotting Distance (SPOT)

The SPOT module predicts maximum spot fire distance from torching trees or burning piles of debris, given a description of the terrain, forest cover, and windspeed. Maximum spotting distance predictions are useful in writing prescriptions, locating the fire line, and positioning "spot fire chasers."

Albini (1979) developed and later (1981) extended the basic model. Chase (1981) wrote a program for the TI-59. Rothermel (1983) discusses the spotting problem in general and presents a simplified nomogram solution for field use. An additional model for predicting spotting distance from spreading surface fires has been developed (Albini 1983), but is not yet in BEHAVE. It has been programmed for the TI-59 (Chase 1984), however, and will be part of the next BEHAVE update.

The maximum spotting distance calculation can be applied under conditions of long-range spotting. In this case, embers are carried well beyond the fireline and start new fires that for some time grow and spread independent of the originating fire. The spotting model is applicable under conditions of intermediate fire severity in which spotting distance up to a mile or two might be expected. The model does not apply to those extreme cases in which spotting may occur up to tens of miles from the main front, as in running crown fires, fires in heavy slash or chaparral under extreme winds, and fires in which fire whirls loft burning material high into the air.

It is also important to recognize factors that are **not** included in the model. The model does not address the probability of trees torching out, but rather what would happen if trees torch out. The model does not include probability of spot fire ignition, that is, whether the firebrand material lands in an area with easily ignited fuels, and whether enough spark or ember remains to cause ignition.

The prediction is for **maximum** spotting distance because ideal conditions are assumed. The wind is assumed to be blowing steadily in one direction. Firebrands are assumed to be sufficiently small to be carried some distance, yet

large enough to still be viable when coming to rest. Any variation from the ideal assumed in the model would serve only to decrease the spot-fire distance. If a source produces 20 firebrands, 19 of which fall within 2 ch of the source and one that travels a mile, it is the "one" that we are predicting. We are calculating "maximum spotting distance" under "ideal" conditions.

The firebrand may have come from torching trees which produce a transitory flame. The firebrand source can also be a group of trees torching together if they produce one flame. This does not include spotting from crown fires, in which case the fire is spreading from tree to tree with a different type of flame structure. The firebrand may also come from a burning pile of debris which produces a continuous flame. This may be a pile of logging slash or a jackpot of debris.

The input of mean cover height is intended to characterize the general forest cover of the terrain as it influences the wind field that will transport the firebrand. If the area has broken forest cover, half the treetop height of the forest-covered portion can be entered as the mean cover height. Zero can be used if the firebrand will be traveling over short grass, bare ground, or water. The windspeed required by the model is the 20-ft windspeed. That means 20 ft above the surface, which in a forested area is 20 ft above the treetops (not the ground).

Mountainous terrain is assumed to look like a wash-board (a sine curve) (fig. 18). Ridgetop-to-valley-bottom elevational difference, and ridgetop-to-valley-bottom horizontal distance, are used to define the shape. Elevational difference is entered in feet, and is used only to a multiple of 1,000 (0, 1,000, 2,000, 3,000, 4,000). Horizontal distance is entered in miles as would be shown on a map. There are four choices for spotting source, depending on the location of the torching tree or burning pile in relation to the wind direction: ridgetop; midslope, leeward side; valley bottom; midslope, windward side.

When the firebrand source is a torching tree, a description of the tree is needed because the flame descriptors are based on the conformation of the crown. The descriptors include species, d.b.h., height, and number of trees. The descriptors are assumed to be the same for every tree in a group of trees torching together. Only those tree species for which good foliage weight data were available are included. Additional species may be added if appropriate data become available. Until that time, you must choose one of the species on the list based on similarity. For example, grand fir can be used for noble, red, and Pacific silver firs, subalpine fir for white fir, western white pine for sugar pine and Monterey pine, and ponderosa pine for Jeffrey, Coulter, and Digger pine.

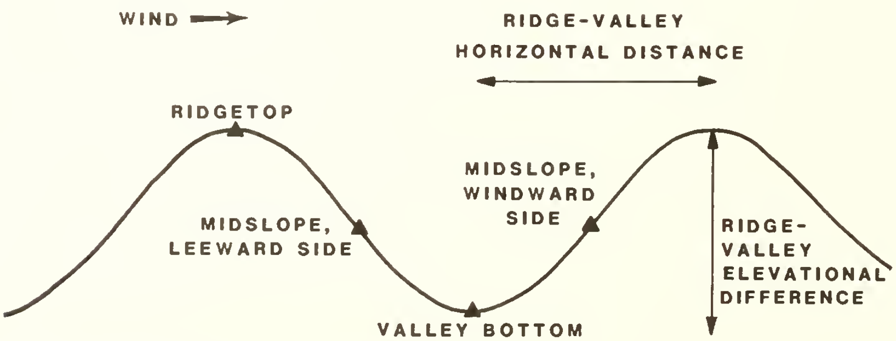

Figure 18.—Mountainous terrain and spotting source location for the maximum spotting distance model.

Continuous flame height is a required input if the source of the firebrand is a burning pile. This is the distance from the ground to the tip of the flame as illustrated in figure 19.

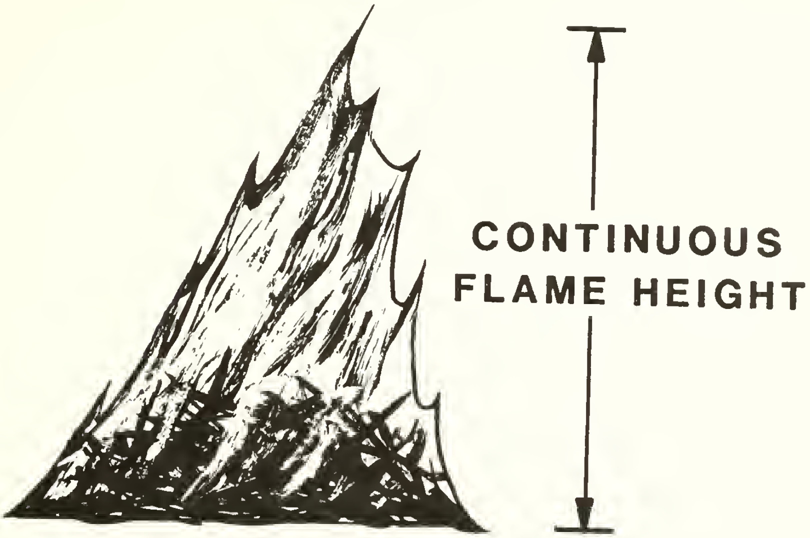

Figure 19.—Continuous flame height for the pile-burning option is the distance from the ground to the tip of the flame.

A Dispatch Example (DISPATCH)

FIRE1 is designed to be flexible enough to be used for a variety of applications, one of these being dispatch of initial attack forces. The keywords allow this flexibility. In a dispatch situation, however, when things are rushed, a more streamlined system would be appropriate. When the inputs are available, DISPATCH can be run in under a minute. The keyword DISPATCH is essentially an automatic link of DIRECT, SIZE, and CONTAIN minus some of the options.

—Only single values can be input, that is, table output is not possible.

—The two-fuel-model concept cannot be used.

—One-hour, 10-hour, 100-hour fuel are all assumed to have the same moisture content.

—Live woody and live herbaceous fuel moisture are assumed to be the same.

—Live fuel moisture is always requested, even if there is no live fuel in the current fuel model.

—Twenty-foot windspeed and wind adjustment factor are input rather than midflame windspeed. The 20-ft wind might be available from a weather report, with wind adjustment factor being preassigned and noted on a map.

—Wind and spread directions are not requested. All calculations are for upslope spread with the wind.

—The containment calculations require line-building rate as input; final fire size is calculated.

—The containment calculations are done for both head and rear attack.

—The containment calculations are not done if the calculated fireline intensity indicates that the fire will be too intense for direct attack.

An example DISPATCH run is included in appendix A.

APPLICATION

Within the limits imposed by the mathematical models described in the previous section, application of BEHAVE is essentially up to the user. Running the programs is easy. But understanding the basis of the predictions and applying them properly requires skill.

Computer systems have played an important role in fire management activities (Rothermel 1980). A computer does not tire of routine calculations. Given a set of data, it will be consistent in coming up with the same answer. (The same cannot be said for humans.) Systems offer an organized way of looking at things. An individual's experience can be applied to wildfire predictions, but it is hard to apply this type of knowledge to planning or analysis situations.

BEHAVE can be viewed as an expert assistant (Andrews and Latham 1984), but the fire manager always makes the final decision. Predictions from the computer must be tempered with real-world fire experience. BEHAVE will willingly process numbers that are supplied and then produce impressive-looking tables. But what do the predictions mean? What is a flame length of 4.2 ft? It is vital that the fire manager make interpretations in terms of the application at hand.

Decisions based on predictions must consider the resolution of the input that is used. Consider windspeed. In predicting spread rate, the value for midflame windspeed might be obtained by direct measurement near the fire. It might be estimated from a spot weather forecast or even from a general weather forecast. For planning purposes a range of windspeeds might be used: "What is the predicted rate of spread for a range of windspeeds from 2 to 10 mi/h?"

BEHAVE differs somewhat from other fire management systems because of the flexibility of design. Many others were designed for a single specific purpose. The following discussion of possible applications of BEHAVE illustrates its flexibility. I will specifically cover use of BEHAVE for dispatch, wildfire, prescribed fire, and training.

Dispatch

Initial attack dispatch is an appropriate application of fire behavior prediction models. At first report of a smoke, a dispatcher may have no information about the fire other than location. Nevertheless, fire behavior can be predicted from information available from maps, weather reports, and so on.

Although it takes less than a minute to enter data into DISPATCH and get predictions, deciding what input values to use will take additional time that in some cases cannot be afforded. Whether calculations are done at the time of a fire call will depend on response time standards.

As mentioned in an earlier section, the DISPATCH module of FIRE1 is only an example of how BEHAVE could be used in a dispatch office. An alternative to using DISPATCH at the time of a fire report is to do calculations using DIRECT, SIZE, and CONTAIN in the morning based on weather forecasts. Tables of predictions would then be available for use during the day as conditions change.

Wildfire

Wildfire prediction was the initial application of the fire behavior prediction system. The system was developed through the Fire Behavior Officer (FBO) S-590 course utilizing tables and nomograms. Refinement of the system was based on field application. Methods are published in "How to Predict . . ." (Rothermel 1983). These methods are automated in BEHAVE. Given that there is computer access in the fire camp, BEHAVE can be a great aid to the FBO in predicting wildfire behavior.

The well-established methods for predicting wildfire growth and intensity require extensive fire experience. The FBO course emphasizes the final products of the written fire behavior forecast, oral briefings to the fire team, and a map of predicted fire growth. An important aspect of using predictions for real-time wildfire prediction is translating calculated values into a form that can be used by the plans chief. A briefing is no place to report that the predicted fireline intensity is 537 Btu/ft/s.

Some aspects of wildfire can be predicted using models, others cannot. BEHAVE provides predictions of spread rate, flame length, and intensity of surface fires. Fireline intensity can be used to indicate the likelihood of severe fire behavior; and spotting distance can be predicted. However, none of the models in BEHAVE can be used to predict the behavior of crown fires. Other aspects of fire behavior do not readily lend themselves to mathematical models. They are best handled by personal experience and "rules-of-thumb." For example, a person can learn to recognize conditions that can lead to the formation of fire whirls.

In addition to an FBO's predictions for the fire team, fire behavior predictions can be used to make initial decisions on the appropriate suppression response on a wildfire. This means the kind, amount, and timing of suppression action on a wildfire that most efficiently meets fire management direction under current and expected burning conditions. It may range in objective from prompt control to confinement (FSM 5105 7/83 AMEND 67). Suppression action could be minimal, and may be limited to surveillance.

Prescribed Fire

In current Forest Service terminology, prescribed fire is divided into two major categories: planned and unplanned ignition (FSM 5105 7/83 AMEND 67). In both cases an approved plan must be in effect before the fire can take place. Fire behavior predictions can be an important element in the plan.

UNPLANNED IGNITION PRESCRIBED FIRE

This category of fire includes fires that are started at random, generally by lightning. If ignition occurs in an area that is covered by an approved fire management plan when conditions are within the prescription, the fire is considered a prescribed fire. Otherwise it is a wildfire. BEHAVE can be used to set the prescription and to predict the behavior of an on-going fire (Andrews and Burgan 1985).

Planning.—Unplanned ignition prescribed fires may have the potential to burn for weeks or even months. Setting up the prescription can involve looking at historical fire occurrence and weather to determine how large fires would have gotten if suppression action had not been taken. This kind of gaming was used in developing the Absaroka-Beartooth Wilderness Plan (USDA Forest Service 1982). This involves using BEHAVE and FBO techniques to project fire growth.

It is not always necessary to map an area covered by a fire management plan by custom fuel models. It is appropriate, however, if there are large areas of the same fuel type not matched by one of the standard 13 NFFL fuel models. Even small areas might deserve the effort that it takes to design a custom fuel model if it is in a critical location where the best possible fire behavior predictions are required. But for an area that is large and varied, such as the Absaroka-Beartooth Wilderness, it is not cost effective to map the entire area with custom fuel models. It may be possible to build a fuel model after an ignition when the fire is expected to last for weeks and daily projections are desired. Even if projections of growth are not critical, this offers a good opportunity to build and refine fuel models with immediate feedback on success.

Real-Time Prediction.—Unplanned ignition prescribed fires offer a unique opportunity to apply fire behavior prediction technology developed for wildfires or free-burning fires on which no suppression action is being taken. Monitoring of the fire will of course involve observing what the fire is doing. But monitoring could also include projecting what the fire is expected to do the next day. This would be especially important if the fire is nearing a boundary of the area included in the management plan. Contingency plans can be based on fire behavior predictions. These techniques were used on the Independence Fire of 1979 as documented by Andrews (1980) and Keown (1985).

PLANNED IGNITION PRESCRIBED FIRE

Fires that are started by a deliberate management action are planned ignition prescribed fires. This is the traditional kind of prescribed fire, and the only kind that many fire managers are associated with.

Pattern of Ignition.—The option in DIRECT of being able to calculate the behavior of a fire in a direction other than that of maximum spread can, in some limited cases, be used to determine the preferred pattern of ignition. Exhibit 21 shows the predictions for a head fire, flanking fire, and backing fire. If scorch height (which is related to flame length) (Van Wagner 1973) is an important factor in a prescription, then the predicted flame length for various spread directions can be used to determine the preferred pattern of ignition. (Scorch height, SCORCH, will be added to BEHAVE later.) In this example, a head fire would result in unacceptably high flame lengths. A backing fire gives acceptable flame lengths but the rate of spread is quite slow. A flanking fire also gives acceptable flame lengths, but with a higher rate of spread. Based on these predictions, the decision might be made to ignite the fire in a strip down the slope, letting the fire spread to the sides.

```
1--FUEL MODEL                          12 -- MEDIUM LOGGING SLASH
2--1-HR FUEL MOISTURE, %                5.0
3--10-HR FUEL MOISTURE, %               6.0
4--100-HR FUEL MOISTURE, %              7.0
7--MIDFLAME WINDSPEED, MI/H             4.0
8--PERCENT SLOPE                       20.0
9--DIRECTION OF WIND VECTOR             0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD                 0.0   90.0 180.0
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL

SPREAD   I RATE OF   HEAT PER     FIRELINE   FLAME   REACTION    EFFECT.
DIRECT.  I SPREAD   UNIT AREA    INTENSITY  LENGTH  INTENSITY    WIND
 (DEG)   I (CH/H)  (BTU/SQ.FT)  (BTU/FT/S)   (FT)  (BTU/SQFT/M) (MI/H)
         I
         I
   0.    I   13.      2302.         528.      8.0     6863.        4.3
         I
  90.    I    2.      2302.          65.      3.1     6863.        0.0
         I
 180.    I    1.      2302.          34.      2.3     6863.        0.0
```

Exhibit 21.—Fire behavior predictions for a head, flanking, and backing fire.

The behavior of the fire is often controlled by the pattern of ignition. One of the basic assumptions of the fire spread model is thereby violated because these fires are not free-burning, steady-state fires spreading independent of the source of ignition. Nevertheless, with care and experience, steady-state fire behavior predictions can be used as a baseline for prescribed fire planning. These predictions can be viewed as what the fire would be expected to do on its own. The pattern and method of ignition can then be used to increase or decrease the fire behavior. For example, strips could be ignited so that the fire

is never able to reach its full steady-state potential. On the other hand, one line of fire could be used to create indrafts that effectively increase the windspeed on another portion of the fire, thereby causing the fire to exceed its steady-state potential. Rothermel (in preparation) presents some fire behavior considerations of aerial ignition.

In some cases, steady-state predictions might indicate that a prescribed fire would be unsuccessful. With an ignition method such as helitorch, however, it is possible to get enough fire into an area fast enough to have a successful burn. If the same ignition is used under conditions when the steady-state predictions are higher, the conditions may actually be too severe for aerial ignition.

At present there are no prediction models or even formalized "rules-of-thumb" to guide the translation of steady-state predictions to actual fire behavior under various firing patterns. Interpretation must be based on personal experience.

Prescription Window.—A prescription sets the conditions under which a burn can be conducted. This often includes acceptable ranges for temperature, relative humidity, windspeed, and so on. When prescription limits occur simultaneously on the high flammability side, a fire may be hotter than desirable. The converse is true on the low flammability side. It is possible to increase the number of potential burning days by looking at tradeoffs between variables. An approach in setting up a prescription window is to work backwards, deciding what the desired steady-state fire behavior is, then determining what conditions would cause it.

Exhibit 22 gives flame length predictions for ranges of 1-h moisture and midflame windspeed. Each table is for a different live fuel moisture. Conditions that lead to flame length predictions of 2 to 4 ft are blocked out, showing the tradeoff between 1-h moisture and midflame windspeed. Notice in exhibit 22B, when 1-h fuels are wet, 12 percent, midflame windspeeds of 2 to 4 mi/h are acceptable. When the 1-h fuels are dry, 4 percent, the acceptable windspeed range is 0 to 2 mi/h.

The difference among the three tables shows the predicted results of burning at different times of the year. Exhibit 22A is for live fuel moisture of 300 percent. This would apply to early stages of the growing cycle when foliage is fresh and annuals are developing. Exhibit 22B is for live fuel moisture of 100 percent when new growth is complete. Exhibit 22C gives predictions when all herbaceous fuels are cured (30 percent live moisture).

Since this is a dynamic fuel model, as described in an earlier section on custom fuel models, all of the herbaceous load is still in the live class when the live fuel moisture is 300 percent. Part of the live herbaceous fuel load has been transferred to the 1-h class when the moisture is 100 percent. All of the live herbaceous fuel is considered dead when the live herbaceous moisture is specified to be 30 percent.

```
1--FUEL MODEL                      20 -- DYNAMIC GRASS AND UNDERSTORY
2--1-HR FUEL MOISTURE, %           2.0    4.0    6.0    8.0   10.0   12.0   14.0
3--10-HR FUEL MOISTURE, %          5.0
4--100-HR FUEL MOISTURE, %         5.0
5--LIVE HERBACEOUS MOIS, %       300.0
7--MIDFLAME WINDSPEED, MI/H        0.0    1.0    2.0    3.0    4.0    5.0    6.0
8--PERCENT SLOPE                  10.0
9--DIRECTION OF WIND VECTOR        0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD            0.0  (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL
```

A.

FLAME LENGTH, FT

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
2.	1.9	2.4	3.3	4.3	5.2	6.2	7.2
4.	1.6	2.0	2.8	3.6	4.5	5.3	6.1
6.	1.5	1.9	2.6	3.3	4.1	4.9	5.6
8.	1.4	1.8	2.5	3.2	3.9	4.6	5.3
10.	1.3	1.7	2.3	3.0	3.7	4.3	5.0
12.	1.1	1.4	1.9	2.5	3.0	3.6	4.1
14.	0.4	0.6	0.8	1.0	1.2	1.4	1.7

B.

FLAME LENGTH, FT

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
2.	2.6	3.2	4.4	5.8	7.1	8.4	9.7
4.	2.2	2.7	3.7	4.9	6.0	7.1	8.2
6.	2.0	2.5	3.4	4.4	5.5	6.5	7.5
8.	1.9	2.4	3.2	4.2	5.2	6.2	7.1
10.	1.8	2.2	3.0	3.9	4.8	5.7	6.6
12.	1.4	1.8	2.5	3.2	3.9	4.7	5.4
14.	0.8	1.1	1.4	1.9	2.3	2.7	3.2

C.

FLAME LENGTH, FT

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.	6.
2.	2.9	3.5	4.9	6.3	7.8	9.3	10.8
4.	2.3	2.9	3.9	5.1	6.3	7.6	8.8
6.	2.1	2.6	3.5	4.6	5.7	6.8	7.8
8.	2.0	2.4	3.3	4.3	5.3	6.4	7.4
10.	1.8	2.2	3.0	3.9	4.9	5.8	6.7
12.	1.4	1.8	2.4	3.1	3.9	4.6	5.4
14.	0.7	0.9	1.2	1.6	1.9	2.3	2.7

Exhibit 22.—DIRECT runs can be used to define a prescription window; (A) live herbaceous fuel moisture = 300 percent; (B) live herbaceous fuel moisture = 100 percent; (C) live herbaceous fuel moisture = 30 percent.

These tables use 1-h fuel moisture rather than 10-h moisture for good reason. Moisture content of the 1-h fuels has much more effect on the rate of spread and flame length predictions than does 10-h. (See exhibit 15 for an example of the relative effects.) Many prescribed burners put ½-inch sticks (10-h fuel) on a site to monitor trends in fuel moisture. Prescription windows might include limits on the moisture of fuel 10-h and larger for burnout and fuel consumption, smoke production, fire effects considerations, or because of experience of the burner. But 10-h moisture should not be used to set a prescription window that is based on flame length or rate-of-spread predictions.

Although the tables in exhibit 22 show the tradeoff among only three variables (1-h, live, wind) as they affect flame length, this integrates a lot of information. Live fuel moisture reflects time of year and 1-h moisture integrates many site and weather variables, including temperature, relative humidity, and precipitation. Although "1 hour timelag" indicates a short response time, the new 1-h model uses weather information from up to 7 previous days to predict the moisture of the fine fuels less than ¼-inch in diameter. The 1-h moisture model provides a consistent way of integrating the effects of many variables into a single number that can be used as a prescription variable as shown in exhibit 22. There are tradeoffs in conditions that lead to a 1-h moisture value, just as there are tradeoffs in wind and moisture that lead to a flame length value. The 1-h fuel moisture model now in SITE will be available in the next BEHAVE update in a module by itself (MOISTURE). Table and graphic output will be available, making it easier to use in prescription writing.

It is possible to show other fire behavior limitations on the same table (exhibit 22B). For example, it may not be desirable to burn under low 1-h moisture conditions (2 percent or less) no matter what the flame length projections are because of the high risk of a firebrand out of the area causing a spot fire. (Probability of Ignition, IGNITE, will be added to BEHAVE later.) Burning under high windspeeds (5 mi/h or greater) may not be acceptable because of the chance of a firebrand blowing out of the burn area into a critical area (based on spotting distance predictions from SPOT).

These tables are primarily used for fire control aspects of prescribed fire. BEHAVE will help with fire behavior aspects, the constraints, of a prescription. Other considerations depend on the land management objectives of the burn, such as to regenerate trees, increase capacity of wildlife habitat, or protect resources from wildfire. It is possible that conflicts will arise in setting the prescription. An example is the conflict between the objective to minimize fuel consumption by burning at high fuel moistures and the constraint to control smoke production. Resolution of these conflicts must be based on priorities of the objectives and constraints (Brown in preparation).

Contingency Planning.—The contingency plan is a critical element of a prescribed fire plan. If a prescribed fire escapes, it is important to be able to estimate what it will do and what resources must be available to control it. Predicting the behavior of a spot fire outside of the designated burn area is an appropriate application for BEHAVE. All of the predictions currently in the FIRE1 program can be used: SPOT for potential spotting distance, DIRECT or SITE for spread and intensity of the escaped fire, SIZE for the potential fire size in a given time, and CONTAIN for the attack forces that should be on hand in the event of an escape. Of course all of the predictions are limited by the models as described in earlier sections.

Predictions from SPOT can be used to estimate the maximum distance from the burn that a spot fire might be expected to occur. At present the model can

be used if the spotting is from torching trees or from burning piles. The burning piles might be logging slash or natural accumulations of dead and down material encountered in an underburn. It might also be a log deck on the edge of a clearcut. A torching tree might be the source of the firebrand when an occasional tree torches in an underburn or on the edge of a clearcut. Remember that spotting under the conditions covered by the spot model is only one way that a prescribed fire can escape. The fire might just jump the line or spots might be carried outside of the area by a fire whirl.

Sources of firebrands can be indicated on a map with a sketch of potential spotting distance. This map can be used to place patrols for spot fires during the burn. The location can also be used in setting the conditions (fuel model, fuel moisture, wind and slope) to be used in the DIRECT or SITE calculations for spread and intensity of a spot fire.

If DIRECT is used to set up tables to define a prescription window (exhibit 22), then similar tables could be used to predict the behavior of an escaped fire under a range of conditions. Even if the fire inside of the block is controlled by the ignition method, the behavior of an escaped fire should more closely match the DIRECT predictions. If the burn is in a grass or shrub fuel type, it is possible that the same table could be used because the spot will likely be into the same fuel type. On the other hand, if the prescribed fire is in logging slash, the spot fire may be in adjacent timber. Then not only would the fuel model and possibly the slope change, but the canopy cover would cause differences in fuel moisture and midflame windspeed.

The predictions from DIRECT give potential spread rate and intensity. Flame length and fireline intensity can be used for fire suppression interpretations, giving an indication of whether direct attack would be successful. And if the escaped fire is in timber, this will indicate whether torching and other severe fire behavior is probable.

The SIZE calculations indicate how large a spot fire would be expected to get in a given period of time. The time would be based on how long you think it would take your forces to get to the fire and begin suppressing it.

CONTAIN can then be used to estimate the attack forces that should be available to contain the spot fire at a specified size. The size is set at whatever you decide is acceptable. The smaller the size, the more people that need be available.

The DIRECT, SIZE, CONTAIN run shown in exhibit 20 is the sequence that would be used for contingency plan predictions.

Custom Fuel Models.—Custom fuel models are not needed for every block to be burned. A single fuel model can be used for many situations. Development of a new fuel model is more involved than sampling the fuel in an area, "plugging" it into the computer, and getting a fuel model. A vital step is incorporating the fire experience of the user in this general fuel type in the test and refinement of the fuel model (TSTMDL program of the FUEL subsystem of BEHAVE). The 13 NFFL fuel models are adequate for many decisions. In some cases, however, none of the 13 models fit the situation. For example, logging slash with a significant component of live shrubs and herbaceous fuels may require a custom fuel model.

Fire Effects

A change in emphasis from strictly fire control to fire management brings about an increased need for predicting fire behavior as it relates to fire effects. Fire effects includes such things as seed survival and vegetation response after a fire. BEHAVE as it now stands has very limited application to fire effects.

Because the fire spread model was designed to predict the growth of a fire for fire suppression applications, it characterizes the behavior in the flaming front. Therefore, it is of limited use for predicting fire effects. Nevertheless, a few such predictions are possible. For example, scorch height has been correlated to fireline intensity (Van Wagner 1973), which relates well to flame length. In general, flame length and fireline intensity are best related to the effect of fire on items in the flame and in the hot convective gases above the flame. In light fuels, heat per unit area could be used to measure heat directed to the surface and related to fire effects in the duff and soil (Rothermel and Deeming 1980).

To illustrate why flame length is a poor indicator of below-ground fire effects (soil temperature), consider the two points plotted on the fire characteristics chart in figure 20. Both fires have the same fireline intensity and flame length. But, fire A is a fast-spreading fire, with a low heat per unit area, while fire B is a slow-spreading fire, with a high heat per unit area. Fire A could be in grass and fire B in logging slash. The slow-moving fire B will concentrate considerable heat on the site as compared to the fast-moving fire A.

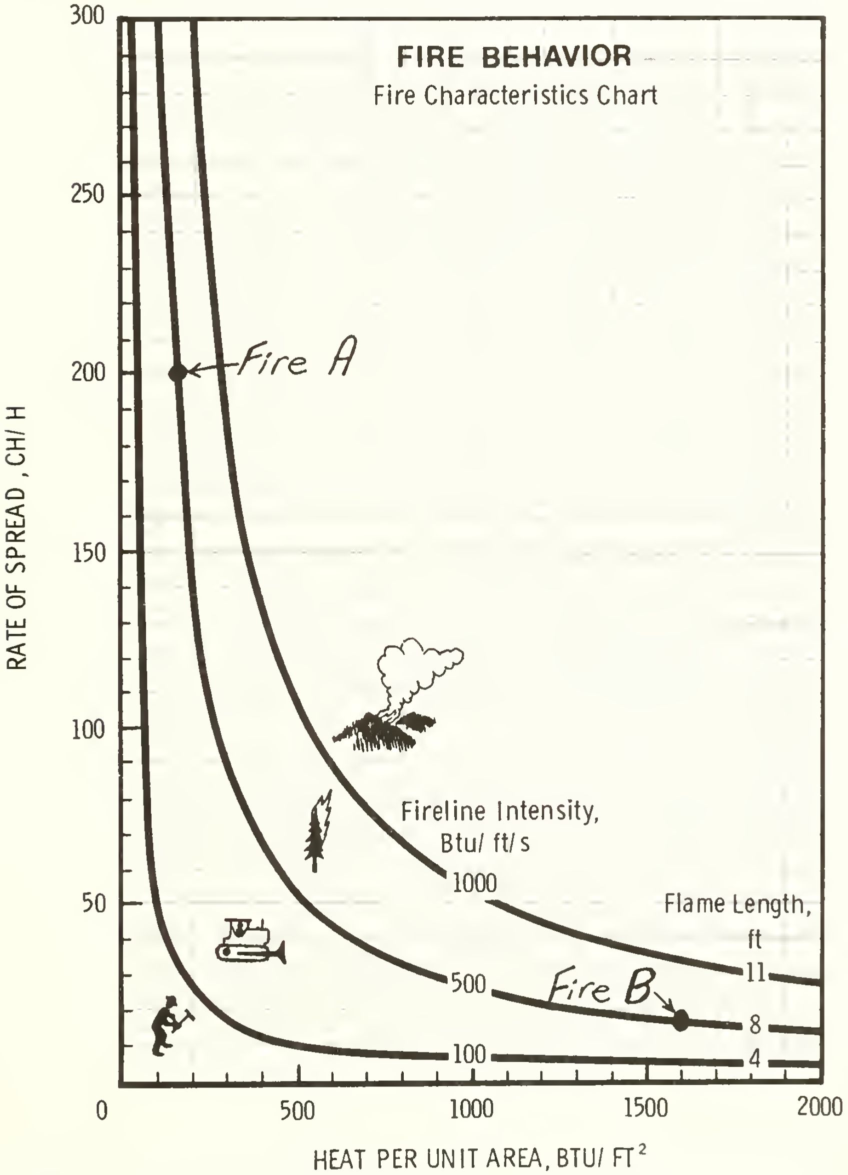

Figure 20.—Fire A and fire B have the same flame length and fireline intensity, but very different rate of spread and heat per unit area.

Many aspects of fire effects are dependent upon the fire behavior after the flaming front has passed, in the burnout of large fuels and smoldering combustion of the duff. Research is in progress in these areas.

Any new prediction models that are added to BEHAVE will likely be limited to fire **behavior**. Fire behavior can be modeled based on physical principles. Fire effects are primarily related to biological systems and the same kind of modeling does not apply. For example, heat flux and time-temperature models might be developed and added to BEHAVE; the relationship to seed and root survival will not.

More fire effects studies are being related to quantitative measures of fire behavior, rather than just a record of fire or no-fire, hot or cool, spring or fall burn. This, in addition to work on mathematical fire behavior models that are designed to be related to fire effects, should strengthen the link between fire behavior and fire effects in the future.

Training

BEHAVE has a place in both classroom training and on-the-job training. BEHAVE is now being included in college curricula to train new fire professionals. Besides giving newcomers a head start at becoming fire behavior experts, BEHAVE can also give oldtimers a new perspective on fire. They begin to translate their "feel for fire" into quantitative terms that can be better communicated to others.

BEHAVE can be used as part of training in relation to any of the specific applications discussed above. It is especially useful for "what if" games. For example, it might be used to train a seasonal dispatcher who has minimal fire experience. BEHAVE offers a focal point for discussion and helps illustrate the factors that are important in affecting fire behavior.

Before an individual uses BEHAVE as an operational fire management tool, he or she should spend some time on personal training. I am not referring to operation of the programs, but rather to using BEHAVE enough to know how the models can be applied. This involves looking at the effect of a change in an input value on the predictions and getting a feel for what the prediction models in BEHAVE can do.

BEHAVE and Other Computer Programs

As shown by the preceding discussion on applications, BEHAVE is a flexible system. When used in conjunction with personal fire experience, it can be used for many aspects of fire management. There are other special purpose computer programs, however, that have a place in fire management activities (Rothermel 1980).

The most prominent might be the National Fire-Danger Rating System (NFDRS) (Deeming and others 1977). It is basically a seasonal weather processor designed to give indexes related to fire potential. Its primary application is broad-area fire planning. Details on NFDRS are given in appendix D. Another system related to fire behavior is the National Fuel Appraisal Process (Radloff and others 1982), which is a method of evaluating the fire hazard aspects of fuel management alternatives. The index of fire hazard used is "expected area burned per year." The Fuel Appraisal Process is based on Rothermel's (1972) fire spread model, as are NFDRS and BEHAVE. But the packaging and application of the systems are very different.

In some cases, BEHAVE will be incorporated into larger computer systems. The Forestry Weather Interpretation System (FWIS) (Paul 1981) includes a fire behavior prediction component (which will be BEHAVE) as well as weather observations and forecasts, smoke management, and air quality. FWIS is

primarily used in the southeastern United States. Another system that will incorporate BEHAVE is the Bureau of Land Management's Initial Attack Management System (IAMS) (German 1984). The goal of the IAMS system is to provide the local district and State fire managers all the fire-related management information they need, in real time, on which to base their fire suppression decisions. In addition, IAMS will provide a means for short- and long-range fire and resource management planning and research.

This is not meant to be an exhaustive list of computer programs available for fire management activities. It should, however, give you some perspective on how BEHAVE can be used as a fire management tool.

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APPENDIX A: EXAMPLE USER SESSION WITH THE FIRE1 PROGRAM OF THE BEHAVE SYSTEM

The following is a computer printout of a user session with the FIRE1 program of the BEHAVE system. It provides an overview of how the program works: how to choose a module, enter and change input, obtain output, and so on.

Lines that begin with a > (the prompt symbol) were typed by the user. All others were printed by the computer. The prompt symbol may be different on another computer.

Getting access to the program is a function of the computer being used and therefore is not described in this manual.

```
WELCOME TO THE
   BEHAVE SYSTEM
      BURN SUBSYSTEM
         FIRE1 PROGRAM (VERSION 2.1 -- SEPT 1984)

DEVELOPED BY THE
   FIRE BEHAVIOR RESEARCH WORK UNIT
   NORTHERN FOREST FIRE LABORATORY
   MISSOULA, MONTANA

ARE YOU USING A TERMINAL WITH A SCREEN ? Y-N
>N

TYPE 'CUSTOM' IF YOU ARE GOING TO USE CUSTOM FUEL MODELS.

FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
         KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>DIRECT

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
         HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(1) FUEL MODEL ? 0-99 OR QUIT
      (ENTER 0 FOR TWO FUEL MODEL CONCEPT INPUT.)
>12.1

NON-INTEGER VALUE =          12.1
DOESN'T MAKE SENSE. TRY AGAIN.

(1) FUEL MODEL ? 0-99 OR QUIT
      (ENTER 0 FOR TWO FUEL MODEL CONCEPT INPUT.)
>12

(2) 1-HR FUEL MOISTURE, % ? 1-60
>5.25

ILLEGAL INPUT:5.25
TRY AGAIN.

(2) 1-HR FUEL MOISTURE, % ? 1-60
>5.2

(3) 10-HR FUEL MOISTURE, % ? 1-60
>70

THE VALUE     70.0
IS OUTSIDE THE LEGAL RANGE       1.0 TO     60.0
TRY AGAIN.

(3) 10-HR FUEL MOISTURE, % ? 1-60
>7
```

The version number will change as the program is updated.

Specify the module that you want to use.

All of the input required for the DIRECT module will be requested.

Immediate error checking. The question is reasked until you give a valid answer.

If a fractional value makes sense, it can be entered to no more accuracy than tenths (one decimal point)

Valid answers are always listed after the question mark.

```
(4) 100-HR FUEL MOISTURE, % ? 1-60
>M

ILLEGAL INPUT:M
TRY AGAIN.

(4) 100-HR FUEL MOISTURE, % ? 1-60
> 7
```

Input must be entered without imbedded blanks.

```
ILLEGAL INPUT: 7
TRY AGAIN.

(4) 100-HR FUEL MOISTURE, % ? 1-60
>7

(7) MIDFLAME WINDSPEED, MI/H ? 0-99
>5.

(8) PERCENT SLOPE ? 0-100
>10
```

Integers can be entered with or without a decimal point.

```
(9) DIRECTION OF WIND VECTOR,
     DEGREES CLOCKWISE FROM UPHILL ? 0-360
>0

(10) DO YOU WANT FIRE BEHAVIOR PREDICTIONS FOR
     THE DIRECTION OF MAXIMUM SPREAD ? Y-N
>Y
```

This indicates that you want predictions for the usual "upslope spread with the wind"

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

You should alwas <u>list</u> the input before a run.

```
 1--FUEL MODEL                      12 -- MEDIUM LOGGING SLASH
 2--1-HR FUEL MOISTURE, %          5.2
 3--10-HR FUEL MOISTURE, %         7.0
 4--100-HR FUEL MOISTURE, %        7.0
 7--MIDFLAME WINDSPEED, MI/H       5.0
 8--PERCENT SLOPE                 10.0
 9--DIRECTION OF WIND VECTOR       0.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD            0.0   (DIRECTION OF MAX SPREAD)
    CALCULATIONS
     DEGREES CLOCKWISE
      FROM UPHILL
```

Summary of the input you just entered.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

To do the calculations and print the results.

```
     RATE OF SPREAD, CH/H-----------       14.
     HEAT PER UNIT AREA, BTU/SQ.FT--     2265.
     FIRELINE INTENSITY, BTU/FT/S---      593.
     FLAME LENGTH, FT---------------        8.5
     REACTION INTENSITY, BTU/SQ.FT/M    6751.
     EFFECTIVE WINDSPEED, MI/H------        5.1
```

The fire behavior predictions.

```
IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'
```

We will try this later

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      SIZE
>INPUT
```

Enter a whole new set of input to DIRECT.

```
(1) FUEL MODEL ? 0-99 OR QUIT
      (ENTER 0 FOR TWO FUEL MODEL CONCEPT INPUT.)
>2

(2) 1-HR FUEL MOISTURE, % ? 1-60
>2,20,2
```

Starting value, Ending value, Step size

```
A MAXIMUM OF 7 VALUES ARE ALLOWED.
```

Limit due to screen size

```
THE FOLLOWING VALUES WILL BE USED
   2.0     4.0     6.0     8.0    10.0    12.0    14.0
OK ? Y-N
>Y
```

For your approval.

```
(3) 10-HR FUEL MOISTURE, % ? 1-60
>5

(4) 100-HR FUEL MOISTURE, % ? 1-60
>6

(5) LIVE HERBACEOUS MOIS, % ? 30-300
>100

(7) MIDFLAME WINDSPEED, MI/H ? 0-99
>5

(8) PERCENT SLOPE ? 0-100
>20

(9) DIRECTION OF WIND VECTOR,
      DEGREES CLOCKWISE FROM UPHILL ? 0-360
>80
```

Cross-slope wind

```
(10) DO YOU WANT FIRE BEHAVIOR PREDICTIONS FOR
      THE DIRECTION OF MAXIMUM SPREAD ? Y-N
>Y

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

```
 1--FUEL MODEL                         2 -- TIMBER (GRASS AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %             2.0   4.0   6.0   8.0  10.0  12.0  14.0
 3--10-HR FUEL MOISTURE, %            5.0
 4--100-HR FUEL MOISTURE, %           6.0
 5--LIVE HERBACEOUS MOIS, %         100.0
 7--MIDFLAME WINDSPEED, MI/H          5.0
 8--PERCENT SLOPE                    20.0
 9--DIRECTION OF WIND VECTOR         80.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD              DIRECTION OF MAXIMUM SPREAD
     CALCULATIONS                      TO BE CALCULATED
     DEGREES CLOCKWISE
      FROM UPHILL
```

Each value is used in the calculations So the output is in the form of a table.

Last time it was obviously zero. This time it has to be calculated

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

These are the same values calculated in the prev. run.

1-HR MOIS (%)	I	RATE OF SPREAD (CH/H)	HEAT PER UNIT AREA (BTU/SQ.FT)	FIRELINE INTENSITY (BTU/FT/S)	FLAME LENGTH (FT)	REACTION INTENSITY (BTU/SQFT/M)	EFFECT. WIND (MI/H)	MAX SPREAD DIREC (DEG)
2.	I	49.	595.	538.	8.1	4313.	5.0	76.
4.	I	40.	512.	379.	6.9	3713.	5.0	76.
6.	I	36.	477.	314.	6.3	3460.	5.0	76.
8.	I	33.	460.	279.	6.0	3336.	5.0	76.
10.	I	30.	430.	234.	5.5	3119.	5.0	76.
12.	I	24.	357.	154.	4.6	2588.	5.0	76.
14.	I	13.	213.	53.	2.8	1542.	5.0	76.

```
IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      SIZE
>CHANGE
```

You can change one or more input value and leave the rest alone

```
CHANGE WHICH LINE ? 0-10
  (0 MEANS NO MORE CHANGES)
>7
```

Notice that in the above list that line 7 is windspeed.

```
(7) MIDFLAME WINDSPEED, MI/H ? 0-99
>0,5,1

THE FOLLOWING VALUES WILL BE USED
   0.0     1.0     2.0     3.0     4.0     5.0
OK ? Y-N
>Y
```

```
CHANGE WHICH LINE ? 0-10
  (0 MEANS NO MORE CHANGES)
>0
```

This time we changed only windspeed.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

Be sure you have what you think you have.

```
 1--FUEL MODEL                      2 -- TIMBER (GRASS AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %         2.0   4.0   6.0   8.0  10.0  12.0  14.0
 3--10-HR FUEL MOISTURE, %        5.0
 4--100-HR FUEL MOISTURE, %       6.0
 5--LIVE HERBACEOUS MOIS, %     100.0
 7--MIDFLAME WINDSPEED, MI/H      0.0   1.0   2.0   3.0   4.0   5.0
 8--PERCENT SLOPE                20.0
 9--DIRECTION OF WIND VECTOR     80.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD         DIRECTION OF MAXIMUM SPREAD
     CALCULATIONS                 TO BE CALCULATED
     DEGREES CLOCKWISE
      FROM UPHILL
```

Ranges for <u>two</u> input variables

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN

TABLE VARIABLE ? 0-7

 0=NO MORE TABLES          4=FLAME LENGTH
 1=RATE OF SPREAD          5=REACTION INTENSITY
 2=HEAT PER UNIT AREA      6=EFFECTIVE WINDSPEED
 3=FIRELINE INTENSITY      7=DIRECTION OF MAX SPREAD
>1
```

Table output. Pick the prediction that you want to look at.

```
===========================================================================
RATE OF SPREAD, CH/HR
===========================================================================
```

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.
2.	6.	7.	13.	22.	34.	49.
4.	5.	6.	10.	18.	28.	40.
6.	5.	5.	9.	16.	25.	36.
8.	4.	5.	8.	15.	23.	33.
10.	4.	4.	8.	13.	20.	30.
12.	3.	4.	6.	10.	16.	24.
14.	2.	2.	3.	6.	9.	13.

These are the rate of spread predictions for each combination of 1-h moisture and windspeed

```
TABLE VARIABLE ? 0-7

 0=NO MORE TABLES       4=FLAME LENGTH
 1=RATE OF SPREAD       5=REACTION INTENSITY
 2=HEAT PER UNIT AREA   6=EFFECTIVE WINDSPEED
 3=FIRELINE INTENSITY   7=DIRECTION OF MAX SPREAD
>4
```

To see another table.

```
=====================================================================
FLAME LENGTH, FT
=====================================================================
```

1-HR MOIS (%)	MIDFLAME WIND, MI/H 0.	1.	2.	3.	4.	5.
2.	3.1	3.4	4.3	5.6	6.8	8.1
4.	2.7	2.9	3.7	4.7	5.8	6.9
6.	2.4	2.6	3.4	4.4	5.3	6.3
8.	2.3	2.5	3.2	4.1	5.1	6.0
10.	2.1	2.3	3.0	3.8	4.7	5.5
12.	1.8	1.9	2.4	3.1	3.9	4.6
14.	1.1	1.2	1.5	1.9	2.4	2.8

Flame length predictions this time

```
TABLE VARIABLE ? 0-7

 0=NO MORE TABLES       4=FLAME LENGTH
 1=RATE OF SPREAD       5=REACTION INTENSITY
 2=HEAT PER UNIT AREA   6=EFFECTIVE WINDSPEED
 3=FIRELINE INTENSITY   7=DIRECTION OF MAX SPREAD
>0
```

→ Only print the tables you want to see.

```
IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      SIZE
>QUIT
```

← Get out of the DIRECT module.

```
FINISH DIRECT -- BACK TO FIRE1
```

```
[FIRE1] KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>SIZE
```

Choose a different calculation module

```
[SIZE] KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT
```

this time SIZE input will be requested.

```
(1) FORWARD RATE OF SPREAD, CH/H ? .1-500 OR QUIT
>10

(2) EFFECTIVE WINDSPEED, MI/H ? 0-99
>0,6,2

THE FOLLOWING VALUES WILL BE USED
   0.0     2.0     4.0     6.0
OK ? Y-N
>Y

(3) ELAPSED TIME, HR ? .1-8
>1
```

Input when SIZE is independent from DIRECT. (We will link to DIRECT later.)

```
SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST


 1---RATE OF SPREAD, CH/H         10.0
 2---EFFECTIVE WIND, MI/H          0.0    2.0    4.0    6.0
 3---ELAPSED TIME, HR              1.0

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

Shape of the ellipse.

EFFECT. WIND (MI/H)	AREA (AC)	PERIMETER (CH)	LENGTH-TO-WIDTH RATIO	FORWARD SPREAD DISTANCE (CH)	BACKING SPREAD DISTANCE (CH)	MAXIMUM WIDTH OF FIRE (CH)
0.	31.4	63.	1.0	10.0	10.0	20.0
2.	6.9	30.	1.5	10.0	1.5	7.6
4.	4.5	26.	2.0	10.0	0.7	5.4
6.	3.4	24.	2.5	10.0	0.4	4.2

```
SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH SIZE -- BACK TO FIRE1
```

Get out of the SIZE module.

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>CONT

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(1) RUN OPTION ? 1-2 OR QUIT
      1=COMPUTE LINE BUILDING RATE
      2=COMPUTE BURNED AREA
>1

(2) MODE OF ATTACK ? 1-2
      1=HEAD
      2=REAR
>2

(3) FORWARD RATE OF SPREAD, CH/H ? .1-500
>10

(4) INITIAL FIRE SIZE, ACRES ? .1-100
>2,10,2

THE FOLLOWING VALUES WILL BE USED
   2.0    4.0    6.0    8.0   10.0
OK ? Y-N
>Y

(5) LENGTH-TO-WIDTH RATIO ? 1-7
>2

(6) BURNED AREA TARGET, ACRES ? .1-2000
>10

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST



 1--RUN OPTION                   1. COMPUTE LINE BUILDING RATE
 2--MODE OF ATTACK               2. REAR
 3--RATE OF SPREAD, CH/H        10.0
 4--INITIAL FIRE SIZE, ACRES     2.0   4.0   6.0   8.0  10.0
 5--LENGTH-TO-WIDTH RATIO        2.0
 6--BURNED AREA TARGET, AC      10.0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

Now we will run CONTAIN as an independent module.

Only the first four characters of <u>any</u> keyword need be entered.

```
 INITIAL  I  TOTAL    CONTAINMENT   LINE
  FIRE    I  LENGTH      TIME      BUILDING
  SIZE    I  OF LINE    (HOURS)      RATE
 (ACRES)  I   (CH)                  (CH/H)
          I
          I
   2.     I    45.        1.4         33.
          I
   4.     I    42.        0.8         49.
          I
   6.     I    40.        0.5         80.
          I
   8.     I    39.        0.2        172.
          I
  10.     I    -1.       -1.0         -1.

      -1 = INITIAL AREA IS EITHER LARGER THAN OR NEARLY
              EQUAL TO THE BURNED AREA TARGET.
```

The burned area target is 10 acres too. See line 6 in LIST.

```
CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH CONTAIN -- BACK TO FIRE1


FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>SPOT
```

Now let's try the SPOT module.

```
SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(1) FIREBRAND SOURCE ? 1-4 OR QUIT
     1=TORCHING TREES
     2=BURNING PILE
     3=SPREADING SURFACE FIRE
     4=RUNNING CROWN FIRE
>2
```

The questions that are asked depend on the firebrand source.

```
(2) MEAN COVER HEIGHT, FT ? 0-300
      (IF FOREST IS OPEN, DIVIDE BY 2.
       OTHERWISE, RETAIN FULL HEIGHT.)
>50

(3) 20-FOOT WINDSPEED, MI/H ? 0-99
>10,20,2

THE FOLLOWING VALUES WILL BE USED
  10.0   12.0   14.0   16.0   18.0   20.0
OK ? Y-N
>Y
```

```
(4) RIDGE/VALLEY ELEVATIONAL DIFFERENCE, FT ? 0-4000
>1000

(5) RIDGE/VALLEY HORIZONTAL DISTANCE, MI ? 0-4
>1

(6) SPOTTING SOURCE LOCATION ? 0-3
     0=MIDSLOPE, WINDWARD SIDE
     1=VALLEY BOTTOM
     2=MIDSLOPE,LEEWARD SIDE
     3=RIDGETOP
>2

(11) CONTINUOUS FLAME HEIGHT, FT ? 1-100
>30,80,10

THE FOLLOWING VALUES WILL BE USED
  30.0   40.0   50.0   60.0   70.0   80.0
OK ? Y-N
>Y

SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST


 1--FIREBRAND SOURCE              2. BURNING PILE
 2--MEAN COVER HEIGHT, FT        50.0
 3--20-FT WINDSPEED, MI/H        10.0   12.0   14.0   16.0   18.0   20.0
 4--RIDGE/VALLEY ELEVATIONAL 1000.0
      DIFFERENCE, FT.
 5--RIDGE/VALLEY HORIZONTAL       1.0
      DISTANCE, MI.
 6--SPOTTING SOURCE LOCATION      2. MIDSLOPE, LEEWARD SIDE
11--CONTINUOUS FLAME HT, FT      30.0   40.0   50.0   60.0   70.0   80.0

SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

Because there is only one output from SPOT you don't have to specify the table variable.

```
==================================================================
MAXIMUM SPOTTING DISTANCE, MI
==================================================================
```

20-FT WINDSPEED (MI/H)	CONTINUOUS FLAME HEIGHT, FT 30.	40.	50.	60.	70.	80.
10.	0.2	0.2	0.2	0.3	0.3	0.3
12.	0.2	0.2	0.3	0.3	0.4	0.4
14.	0.2	0.3	0.3	0.4	0.4	0.5
16.	0.2	0.3	0.4	0.4	0.5	0.5
18.	0.3	0.3	0.4	0.5	0.5	0.6
20.	0.3	0.4	0.5	0.5	0.6	0.7

```
SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>CHANGE

CHANGE WHICH LINE ? 0-11
  (0 MEANS NO MORE CHANGES)
>1

(1) FIREBRAND SOURCE ? 1-4 OR QUIT
     1=TORCHING TREES
     2=BURNING PILE
     3=SPREADING SURFACE FIRE
     4=RUNNING CROWN FIRE
>3

THIS OPTION WILL BE ADDED LATER.
THE INPUT IS FUEL MODEL, WINDSPEED, AND FIRELINE INTENSITY.
```

Spotting distance from a wind-driven surface fire is part of BURN-Part 2.

```
(1) FIREBRAND SOURCE ? 1-4 OR QUIT
     1=TORCHING TREES
     2=BURNING PILE
     3=SPREADING SURFACE FIRE
     4=RUNNING CROWN FIRE
>4
```

This is included just for emphasis. No current work is addressing this question.

```
WE CAN'T PREDICT SPOTTING DISTANCE FROM A RUNNING CROWN FIRE YET.
A RUNNING CROWN FIRE IS VERY DIFFERENT FROM A TORCHING TREE.

(1) FIREBRAND SOURCE ? 1-4 OR QUIT
     1=TORCHING TREES
     2=BURNING PILE
     3=SPREADING SURFACE FIRE
     4=RUNNING CROWN FIRE
>1

CHANGE WHICH LINE ? 0-11
  (0 MEANS NO MORE CHANGES)
>0
```

I specified "no more changes" But the torching tree option requires more input than does the burning pile option.

```
BECAUSE OF THE CHANGES YOU MADE,
  ADDITIONAL INPUT IS REQUIRED...

(7) TORCHING TREE SPECIES ? 1-6
     1=ENGELMANN SPRUCE
     2=DOUGLAS FIR, SUBALPINE FIR
     3=HEMLOCK
     4=PONDEROSA PINE, LODGEPOLE PINE
     5=WHITE PINE
     6=BALSAM FIR, GRAND FIR
>2

(8) TORCHING TREE DBH, IN ? 5-40
>14

(9) TORCHING TREE HEIGHT, FT ? 10-300
>50

(10) NUMBER OF TREES TORCHING TOGETHER ? 1-30
>2
```

```
SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST


 1--FIREBRAND SOURCE              1. TORCHING TREE
 2--MEAN COVER HEIGHT, FT        50.0
 3--20-FT WINDSPEED, MI/H        10.0   12.0   14.0   16.0   18.0   20.0
 4--RIDGE/VALLEY ELEVATIONAL 1000.0
       DIFFERENCE, FT.
 5--RIDGE/VALLEY HORIZONTAL       1.0
       DISTANCE, MI.
 6--SPOTTING SOURCE LOCATION      2. MIDSLOPE, LEEWARD SIDE
 7--TORCHING TREE SPECIES         2. DOUGLAS FIR, SUBALPINE FIR
 8--TORCHING TREE DBH, IN        14.0
 9--TORCHING TREE HEIGHT, FT     50.0
10--NUMBER OF TREES               2.0
       TORCHING TOGETHER

SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN


        20-FT        I  MAXIMUM
     WINDSPEED       I  SPOTTING
       (MI/H)        I  DISTANCE
                     I    (MI)
                     I
         10.         I    0.2
                     I
         12.         I    0.2
                     I
         14.         I    0.3
                     I
         16.         I    0.3
                     I
         18.         I    0.3
                     I
         20.         I    0.4

SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>TERSE
TERSE PROMPT OPTION SET.

SPOT KEYWORD?
>INPUT

(1) FIREBRAND SOURCE ? 1-4 OR QUIT
>1

(2) MEAN COVER HEIGHT, FT ? 0-300
>50
```

The TERSE mode is set until WORDY is typed.

Valid keywords are not listed.

Code definitions are not listed.

```
(3) 20-FOOT WINDSPEED, MI/H ? 0-99
>10,20,2

THE FOLLOWING VALUES WILL BE USED
  10.0    12.0    14.0    16.0    18.0    20.0
OK ? Y-N
>Y

(4) RIDGE/VALLEY ELEVATIONAL DIFFERENCE, FT ? 0-4000
>1000

(5) RIDGE/VALLEY HORIZONTAL DISTANCE, MI ? 0-4
>1

(6) SPOTTING SOURCE LOCATION ? 0-3
>2

(7) TORCHING TREE SPECIES ? 1-6
>2

(8) TORCHING TREE DBH, IN ? 5-40
>14

(9) TORCHING TREE HEIGHT, FT ? 10-300
>50

(10) NUMBER OF TREES TORCHING TOGETHER ? 1-30
>2

SPOT KEYWORD?
>LIST


 1---FIREBRAND SOURCE              1. TORCHING TREE
 2---MEAN COVER HEIGHT, FT        50.0
 3---20-FT WINDSPEED, MI/H        10.0   12.0   14.0   16.0   18.0   20.0
 4---RIDGE/VALLEY ELEVATIONAL   1000.0
       DIFFERENCE, FT.
 5---RIDGE/VALLEY HORIZONTAL       1.0
       DISTANCE, MI.
 6---SPOTTING SOURCE LOCATION      2. MIDSLOPE, LEEWARD SIDE
 7---TORCHING TREE SPECIES         2. DOUGLAS FIR, SUBALPINE FIR
 8---TORCHING TREE DBH, IN        14.0
 9---TORCHING TREE HEIGHT, FT     50.0
10---NUMBER OF TREES               2.0
       TORCHING TOGETHER

SPOT KEYWORD?
>RUN
```

Code definitions are not listed when you use the TERSE mode.

LIST and RUN look the same whether you are in TERSE or WORDY mode.

```
   20-FT       I  MAXIMUM
 WINDSPEED     I  SPOTTING
   (MI/H)      I  DISTANCE
               I    (MI)
               I
    10.        I    0.2
               I
    12.        I    0.2
               I
    14.        I    0.3
               I
    16.        I    0.3
               I
    18.        I    0.3
               I
    20.        I    0.4

SPOT KEYWORD?
>WORDY
WORDY PROMPT OPTION SET.

SPOT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH SPOT -- BACK TO FIRE1
```

Back to WORDY mode

Now the valid Keywords are listed.

```
FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>SITE

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(1) MONTH OF BURN ? 1-12 OR QUIT
>QUIT

SITE INPUT TERMINATED.

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH SITE -- BACK TO FIRE1
```

Let's try the SITE module.
On second thought, let's wait till later.
This gives you an escape.

```
FIRE1 KEYWORD?
ENTER  DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
       KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>QUIT
```

← *QUIT as a FIRE1 keyword means that you are through running the program.*

```
DO YOU  R E A L L Y  WANT TO TERMINATE THIS RUN? Y-N
>N
```

This gives you an escape.

```
OK.......
```

When you terminate the run, the input you entered is lost.

```
FIRE1 KEYWORD?
ENTER  DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
       KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>DIRECT

DIRECT KEYWORD?
ENTER  INPUT,LIST,CHANGE,RUN,QUIT,
       HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST  <--------------------------------
```

But we didn't terminate, so the DIRECT input we entered earlier is still there

```
 1--FUEL MODEL                      2 -- TIMBER (GRASS AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %        2.0    4.0    6.0    8.0   10.0   12.0   14.0
 3--10-HR FUEL MOISTURE, %       5.0
 4--100-HR FUEL MOISTURE, %      6.0
 5--LIVE HERBACEOUS MOIS, %    100.0
 7--MIDFLAME WINDSPEED, MI/H     0.0    1.0    2.0    3.0    4.0    5.0
 8--PERCENT SLOPE               20.0
 9--DIRECTION OF WIND VECTOR    80.0
     DEGREES CLOCKWISE
      FROM UPHILL
10--DIRECTION OF SPREAD         DIRECTION OF MAXIMUM SPREAD
     CALCULATIONS                 TO BE CALCULATED
     DEGREES CLOCKWISE
      FROM UPHILL

DIRECT KEYWORD?
ENTER  INPUT,LIST,CHANGE,RUN,QUIT,
       HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>CHANGE

CHANGE WHICH LINE ? 0-10
  (0 MEANS NO MORE CHANGES)
>2

(2) 1-HR FUEL MOISTURE, % ? 1-60
>4

CHANGE WHICH LINE ? 0-10
  (0 MEANS NO MORE CHANGES)
>0
```

We will rerun this with a single value for 1-h fuel moisture.

```
DIRECT KEYWORD?
ENTER  INPUT,LIST,CHANGE,RUN,QUIT,
       HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

```
 1--FUEL MODEL                       2 -- TIMBER (GRASS AND UNDERSTORY)
 2--1-HR FUEL MOISTURE, %          4.0
 3--10-HR FUEL MOISTURE, %         5.0
 4--100-HR FUEL MOISTURE, %        6.0
 5--LIVE HERBACEOUS MOIS, %      100.0
 7--MIDFLAME WINDSPEED, MI/H       0.0    1.0    2.0    3.0    4.0    5.0
 8--PERCENT SLOPE                 20.0
 9--DIRECTION OF WIND VECTOR      80.0
      DEGREES CLOCKWISE
       FROM UPHILL
10--DIRECTION OF SPREAD           DIRECTION OF MAXIMUM SPREAD
      CALCULATIONS                  TO BE CALCULATED
      DEGREES CLOCKWISE
       FROM UPHILL

DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

MIDFLAME WIND (MI/H)	I	RATE OF SPREAD (CH/H)	HEAT PER UNIT AREA (BTU/SQ.FT)	FIRELINE INTENSITY (BTU/FT/S)	FLAME LENGTH (FT)	REACTION INTENSITY (BTU/SQFT/M)	EFFECT. WIND (MI/H)	MAX SPREAD DIREC (DEG)
0.	I	5.	512.	48.	2.7	3713.	1.1	0.
1.	I	6.	512.	56.	2.9	3713.	1.4	34.
2.	I	10.	512.	97.	3.7	3713.	2.1	61.
3.	I	18.	512.	168.	4.7	3713.	3.1	71.
4.	I	28.	512.	262.	5.8	3713.	4.0	74.
5.	I	40.	512.	379.	6.9	3713.	5.0	76.

```
IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'
```

OK. This time we will link SIZE to DIRECT.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      SIZE
>SIZE

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(3) ELAPSED TIME, HR. ? .1-8
>1.5

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

Refer to the Keyword Hierarchy (Exhibit 2). Time is the only additional input required for SIZE. Rate of spread and effective windspeed are calculated by DIRECT.

This is given mainly for reference when you are using a screen and the DIRECT output table on the previous page is no longer visible.

```
 1--RATE OF SPREAD, CH/H        OUTPUT FROM DIRECT. RANGE=    5. TO    40.
 2--EFFECTIVE WIND, MI/H        OUTPUT FROM DIRECT. RANGE=   1.1 TO    5.0
 3--ELAPSED TIME, HR            1.5

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

The range for this input variable is carried over from DIRECT.

```
MIDFLAME I    AREA   PERIMETER  LENGTH-   FORWARD   BACKING    MAXIMUM
  WIND   I    (AC)     (CH)     TO-WIDTH   SPREAD    SPREAD     WIDTH
 (MI/H)  I                       RATIO    DISTANCE  DISTANCE   OF FIRE
         I                                  (CH)      (CH)       (CH)
         I
   0.    I     5.3      26.       1.3        7.6       1.7        7.3
         I
   1.    I     6.8      30.       1.3        9.0       1.8        8.1
         I
   2.    I    16.0      46.       1.5       15.5       2.1       11.5
         I
   3.    I    38.2      74.       1.8       26.8       2.6       16.6
         I
   4.    I    78.5     108.       2.0       41.9       3.0       22.3
         I
   5.    I   141.9     150.       2.3       60.6       3.3       28.3

IF YOU WANT TO CONTINUE WITH THE CONTAINMENT CALCULATIONS
  TYPE 'CONTAIN'

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      CONTAIN
>CHANGE

(3) ELAPSED TIME, HR. ? .1-8
>.5,3,.5
```

Since there is only one SIZE input that can be changed, you are not asked for the line number.

```
THE FOLLOWING VALUES WILL BE USED
   0.5     1.0     1.5     2.0     2.5     3.0
OK ? Y-N
>Y

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST

 1--RATE OF SPREAD, CH/H        OUTPUT FROM DIRECT. RANGE=    5. TO    40.
 2--EFFECTIVE WIND, MI/H        OUTPUT FROM DIRECT. RANGE=   1.1 TO    5.0
 3--ELAPSED TIME, HR            0.5   1.0   1.5   2.0   2.5   3.0

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

```
TABLE VARIABLE ? 0-6

 0=NO MORE TABLES          3=LENGTH-TO-WIDTH RATIO
 1=AREA                    4=FORWARD SPREAD DISTANCE
 2=PERIMETER               5=BACKING SPREAD DISTANCE
                           6=MAXIMUM WIDTH OF FIRE
>1

=====================================================================
AREA, ACRES
=====================================================================
MIDFLAME I        ELAPSED TIME TO ATTACK,  HR
  WIND   I
 (MI/H)  I    0.5     1.0     1.5     2.0     2.5     3.0
         I------------------------------------------------------------
         I
  0.     I    0.6     2.4     5.3     9.5    14.8    21.3
         I
  1.     I    0.8     3.0     6.8    12.2    19.0    27.4
         I
  2.     I    1.8     7.1    16.0    28.5    44.6    64.2
         I
  3.     I    4.2    17.0    38.2    68.0   106.2   152.9
         I
  4.     I    8.7    34.9    78.5   139.5   218.0   313.9
         I
  5.     I   15.8    63.1   141.9   252.3   394.2   567.6
```

Area is printed to tenths when any prediction is less than 10 acres.

```
TABLE VARIABLE ? 0-6

 0=NO MORE TABLES          3=LENGTH-TO-WIDTH RATIO
 1=AREA                    4=FORWARD SPREAD DISTANCE
 2=PERIMETER               5=BACKING SPREAD DISTANCE
                           6=MAXIMUM WIDTH OF FIRE
>0
```

Length-to-width-ratio is automatically saved for CONTAIN—even though it is not printed.

```
IF YOU WANT TO CONTINUE WITH THE CONTAINMENT CALCULATIONS
  TYPE 'CONTAIN'
```

Now we will link CONTAIN to SIZE and DIRECT.

```
SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      CONTAIN
>CONTAIN

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT
```

Some of the input required for CONTAIN has been calculated by DIRECT and SIZE.

```
(1) RUN OPTION ? 1-2 OR QUIT
      1=COMPUTE LINE BUILDING RATE
      2=COMPUTE BURNED AREA
>2

(2) MODE OF ATTACK ? 1-2
      1=HEAD
      2=REAR
>1

(7) LINE BUILDING RATE, CH/H ? .1-200
>50
```

```
CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST


 1--RUN OPTION                     2. COMPUTE BURNED AREA
 2--MODE OF ATTACK                 1. HEAD
 3--RATE OF SPREAD, CH/H           OUTPUT FROM DIRECT. RANGE=     5. TO    40.
 4--INITIAL FIRE SIZE, ACRES       OUTPUT FROM SIZE.   RANGE=     1. TO   568.
 5--LENGTH-TO-WIDTH RATIO          OUTPUT FROM SIZE.   RANGE=   1.3 TO    2.3
 7--LINE BUILDING RATE, CH/H    50.0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN

TABLE VARIABLE ? 0-3
 0=NO MORE TABLES
 1=TOTAL LENGTH OF LINE
 2=CONTAINMENT TIME
 3=FINAL FIRE SIZE
>3

===================================================================
FINAL FIRE SIZE, ACRES
===================================================================
MIDFLAME I       ELAPSED TIME TO ATTACK,   HR
  WIND   I
 (MI/H)  I     0.5    1.0    1.5    2.0    2.5    3.0
         I---------------------------------------------------------
         I
   0.    I     1.     3.     7.    12.    19.    28.
         I
   1.    I     1.     4.     9.    16.    25.    37.
         I
   2.    I     3.    11.    24.    43.    68.    97.
         I
   3.    I     8.*   32.*   71.*  127.*  198.*  286.*
         I
   4.    I    -2.*   -2.*   -2.*   -2.*   -2.*   -2.*
         I
   5.    I    -2.*   -2.*   -2.*   -2.*   -2.*   -2.*
         I

            -2 = FORWARD RATE OF SPREAD IS EITHER GREATER THAN
                  OR NEARLY EQUAL TO LINE BUILDING RATE PER FLANK.
                                                            ← Note!
             * = FIRE IS TOO INTENSE FOR DIRECT ATTACK BY
                   HAND CREWS.
                 EQUIPMENT SUCH AS DOZERS, PUMPERS, PLOWS,
                   AND RETARDANT AIRCRAFT CAN BE EFFECTIVE.

TABLE VARIABLE ? 0-3
 0=NO MORE TABLES
 1=TOTAL LENGTH OF LINE
 2=CONTAINMENT TIME
 3=FINAL FIRE SIZE
>0
```

```
CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>CHANGE

CHANGE WHICH LINE ? 0-7
  (0 MEANS NO MORE CHANGES)
>7

(7) LINE BUILDING RATE, CH/H ? .1-200
>30,60,10

THE FOLLOWING VALUES WILL BE USED
  30.0   40.0   50.0   60.0
OK ? Y-N
>Y

CHANGE WHICH LINE ? 0-7
  (0 MEANS NO MORE CHANGES)
>0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

Range input for line building rate.

```
 1--RUN OPTION                  2. COMPUTE BURNED AREA
 2--MODE OF ATTACK              1. HEAD
 3--RATE OF SPREAD, CH/H        OUTPUT FROM DIRECT. RANGE=     5. TO    40.
 4--INITIAL FIRE SIZE, ACRES    OUTPUT FROM SIZE.   RANGE=     1. TO   568.
 5--LENGTH-TO-WIDTH RATIO       OUTPUT FROM SIZE.   RANGE=   1.3 TO    2.3
 7--LINE BUILDING RATE, CH/H   30.0  40.0  50.0  60.0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN

A RANGE OF VALUES IS NOT ALLOWED FOR
LINE BUILDING RATE SINCE TWO OF THE INPUT
VARIABLES FOR DIRECT OR SIZE HAVE ALREADY
BEEN ASSIGNED RANGES.
```

Midflame windspeed and elapsed time

```
CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH CONTAIN LINKED TO SIZE -- BACK TO SIZE
```

Go back one level in the hierarchy of keywords.

```
SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>CHANGE

(3) ELAPSED TIME, HR. ? .1-8
>1
```

Change elapsed time from a range to a single value.

```
SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST

 1--RATE OF SPREAD, CH/H            OUTPUT FROM DIRECT. RANGE=    5. TO    40.
 2--EFFECTIVE WIND, MI/H            OUTPUT FROM DIRECT. RANGE=   1.1 TO    5.0
 3--ELAPSED TIME, HR                1.0

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

It is necessary to rerun SIZE before you can link to CONTAIN.

MIDFLAME WIND (MI/H)	AREA (AC)	PERIMETER (CH)	LENGTH-TO-WIDTH RATIO	FORWARD SPREAD DISTANCE (CH)	BACKING SPREAD DISTANCE (CH)	MAXIMUM WIDTH OF FIRE (CH)
0.	2.4	17.	1.3	5.1	1.2	4.8
1.	3.0	20.	1.3	6.0	1.2	5.4
2.	7.1	31.	1.5	10.4	1.4	7.7
3.	17.0	49.	1.8	17.8	1.7	11.1
4.	34.9	72.	2.0	27.9	2.0	14.9
5.	63.1	100.	2.3	40.4	2.2	18.9

```
IF YOU WANT TO CONTINUE WITH THE CONTAINMENT CALCULATIONS
  TYPE 'CONTAIN'

SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      CONTAIN
>CONTAIN
```

Now it is OK to run CONTAIN.

```
CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST
```

The CONTAIN input is still there, with new values from SIZE.

```
 1--RUN OPTION                      2. COMPUTE BURNED AREA
 2--MODE OF ATTACK                  1. HEAD
 3--RATE OF SPREAD, CH/H            OUTPUT FROM DIRECT. RANGE=      5. TO     40.
 4--INITIAL FIRE SIZE, ACRES        OUTPUT FROM SIZE.   RANGE=      2. TO     63.
 5--LENGTH-TO-WIDTH RATIO           OUTPUT FROM SIZE.   RANGE=     1.3 TO     2.3
 7--LINE BUILDING RATE, CH/H       30.0  40.0  50.0  60.0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

Range input for line building rate is OK now.

```
TABLE VARIABLE ? 0-3
 0=NO MORE TABLES
 1=TOTAL LENGTH OF LINE
 2=CONTAINMENT TIME
 3=FINAL FIRE SIZE
>3

=================================================================
FINAL FIRE SIZE, ACRES
=================================================================
MIDFLAME I        LINE BUILDING RATE, CH/H
  WIND   I
 (MI/H)  I    30.     40.     50.     60.
         I------------------------------------------------------
         I
   0.    I     4.      3.      3.      3.
         I
   1.    I     5.      4.      4.      4.
         I
   2.    I    15.     12.     11.     10.
         I
   3.    I    -2.*    40.*    32.*    28.*
         I
   4.    I    -2.*    -2.*    -2.*    -2.*
         I
   5.    I    -2.*    -2.*    -2.*    -2.*
         I

          -2 = FORWARD RATE OF SPREAD IS EITHER GREATER THAN
                OR NEARLY EQUAL TO LINE BUILDING RATE PER FLANK.

           * = FIRE IS TOO INTENSE FOR DIRECT ATTACK BY
                 HAND CREWS.
               EQUIPMENT SUCH AS DOZERS, PUMPERS, PLOWS,
                 AND RETARDANT AIRCRAFT CAN BE EFFECTIVE.

TABLE VARIABLE ? 0-3
 0=NO MORE TABLES
 1=TOTAL LENGTH OF LINE
 2=CONTAINMENT TIME
 3=FINAL FIRE SIZE
>0

CONTAIN KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH CONTAIN LINKED TO SIZE -- BACK TO SIZE


SIZE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH SIZE LINKED TO DIRECT -- BACK TO DIRECT
```

Refer to the Keyword hierarchy, exhibit 2, to see how we get from CONTAIN linked to SIZE and DIRECT to the DISPATCH module.

```
DIRECT KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>QUIT

FINISH DIRECT -- BACK TO FIRE1



FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>DISPATCH

DISPATCH KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,WORDY,TERSE,PAUSE,NOPAUSE
>INPUT

(1) FUEL MODEL NUMBER ? 1-99 OR QUIT
>2

(2) DEAD FUEL MOIS., % ? 1-60
>5

(3) LIVE FUEL MOIS., % ? 30-300
>100

(4) 20-FT WINDSPEED, MI/H ? 0-99
      (ASSUMED TO BE BLOWING UPHILL)
>10

(5) WIND ADJUSTMENT FACTOR ? .1-1
>.3

(6) PERCENT SLOPE ? 0-100
>15

(7) ELAPSED TIME FROM IGNITION TO ATTACK, HR ? .1-8
>1

(8) LINE BUILDING RATE, CH/H ? .1-200
>50

DISPATCH KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,WORDY,TERSE,PAUSE,NOPAUSE
>LIST

 1 -- FUEL MODEL --------------------     2.-- TIMBER (GRASS AND UNDERSTORY)
 2 -- DEAD FUEL MOISTURE ------------     5. %
 3 -- LIVE FUEL MOISTURE ------------   100. %
 4 -- 20-FT WINDSPEED (UPSLOPE) -----    10. MI/H
 5 -- WIND ADJUSTMENT FACTOR --------     0.3
 6 -- SLOPE -------------------------    15. %
 7 -- ELAPSED TIME FROM IGNITION
        TO ATTACK -------------------     1.0 HR
 8 -- LINE BUILDING RATE ------------    50.0 CH/H

DISPATCH KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,WORDY,TERSE,PAUSE,NOPAUSE
>RUN
```

DISPATCH is essentially an automatic link from DIRECT to SIZE to CONTAIN, without some of the options.

```
    FORWARD RATE OF SPREAD ----------    17.  CH/H
    HEAT PER UNIT AREA -------------    491.  BTU/SQ.FT
    FIRELINE INTENSITY -------------    157.  BTU/FT/S
    FLAME LENGTH --------------------    4.6 FEET

    AREA AT TIME OF ATTACK ----------    16.  ACRES
    PERIMETER AT TIME OF ATTACK -----    48.  CHAINS

THESE PREDICTIONS INDICATE THAT
THE FIRE IS TOO INTENSE FOR DIRECT ATTACK
BY HAND CREWS.  EQUIPMENT SUCH AS DOZERS, PUMPERS,
AND RETARDANT AIRCRAFT CAN BE EFFECTIVE.

  HEAD ATTACK:
    TOTAL LENGTH OF LINE ------------    62.  CHAINS
      (PERIMETER OF BURNED AREA)
    ELAPSED TIME FROM ATTACK
      TO CONTAINMENT ----------------    1.2 HOURS
    FINAL FIRE SIZE -----------------    29.  ACRES

  REAR ATTACK:
    TOTAL LENGTH OF LINE ------------   165.  CHAINS
      (PERIMETER OF BURNED AREA)
    ELAPSED TIME FROM ATTACK
      TO CONTAINMENT ----------------    3.3 HOURS
    FINAL FIRE SIZE -----------------   132.  ACRES

DISPATCH KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,WORDY,TERSE,PAUSE,NOPAUSE
>QUIT

FINISH DISPATCH -- BACK TO FIRE1


FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>SITE <------------------------------------ Now we will try SITE.

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>INPUT

(1) MONTH OF BURN ? 1-12 OR QUIT
>4

(2) DAY OF BURN ? 1 - 31
>5

(3) DO YOU KNOW THE LATITUDE ? Y-N     Sometimes more than one
>Y                                     question is associated
                                       with a line number
(3) LATITUDE, DEG. ? 0-90
>45

SUNSET  = 1822.
SUNRISE =  537. <------------------------ Calculated
```

```
(4) BURN TIME ? 0000-2359
>1390

ILLEGAL INPUT.
THERE ARE 60 MINUTES IN AN HOUR.
TRY AGAIN.

(4) BURN TIME ? 0000-2359
>13

DID YOU MEAN 1300. RATHER THAN 0013. ? Y-N
>Y
```

This program is certainly friendly!

```
(5) DO YOU WANT TO USE THE TWO FUEL MODEL CONCEPT ? Y-N
>N

(5) FUEL MODEL ? 1-99
>1

(10) DO YOU WANT TO ENTER MAP MEASUREMENTS TO
     CALCULATE PERCENT SLOPE ? Y-N
>N

(10) PERCENT SLOPE ? 0-100
>0

(11) ELEVATION OF FIRE LOCATION, FT ? 0-12000
>1000

(12) IS THE ELEVATION DIFFERENCE BETWEEN THE LOCATION OF THE
     FIRE AND THE LOCATION OF THE TEMPERATURE AND HUMIDITY READINGS
     MORE THAN 1000 FT ? Y-N
>N

(14) CROWN CLOSURE, % ? 0-100
       (ENTER THE CLOSURE AS IF THERE WERE FOLIAGE)
>0
```

← *This causes a lot of questions to be skipped.*

```
(21) BURN TIME TEMPERATURE, F ? 33-120 OR QUIT
>78

(22) BURN TIME RELATIVE HUMIDITY, % ? 1-100
>34

(23) BURN TIME 20-FT WINDSPEED, MI/H ? 0-99
>0

FUELS ARE EXPOSED TO THE WIND

WIND ADJUSTMENT FACTOR = .4

(27) BURN TIME CLOUD COVER, % ? 0-100
>0

(28) BURN TIME HAZINESS ? 1-4
       1=VERY CLEAR SKY
       2=AVERAGE CLEAR FOREST ATMOSPHERE
       3=MODERATE FOREST BLUE HAZE
       4=DENSE HAZE
>1
```

1400 conditions (lines 29-33) are set equal to burn time conditions because burn time is 1300 -- between 1200 and 1600.

```
(42) MOISTURE INITIALIZATION OPTION ? 1-5

        1=FINE FUEL MOISTURE KNOWN FOR BURN DAY -1

        2=COMPLETE WEATHER DATA FOR 3 TO 7 DAYS

        3=INCOMPLETE WEATHER DATA
          RAIN THE WEEK BEFORE THE BURN

        4=INCOMPLETE WEATHER DATA
          NO RAIN THE WEEK BEFORE THE BURN
          WEATHER PATTERN HOLDING
          (NO ADDITIONAL INPUT) <----------- Note.

        5=INCOMPLETE WEATHER DATA
          WEATHER PATTERN CHANGING
>4

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST

 1--MONTH OF BURN -------------------------     4.
 2--DAY OF BURN ---------------------------     5.
 3--LATITUDE, DEG. ------------------------    45.

 4--BURN TIME ----------------------------- 1300.

 5--FUEL MODEL ----------------------------     1.
                                              SHORT GRASS (1 FT)


10--SLOPE, % ------------------------------     0.
11--ELEVATION OF FIRE SITE, FT ----------- 1000.
12--ELEVATION DIFFERENCE BETWEEN FIRE
      SITE AND SITE OF T/RH READINGS ------   LESS THAN 1000 FT

14--CROWN CLOSURE, % ----------------------     0.

21--BURN TIME TEMPERATURE, F -------------    78.
22--BURN TIME RELATIVE HUMIDITY, % -------    34.
23--BURN TIME 20-FT WINDSPEED, MI/H ------     0.
24--BURN TIME DIRECTION OF WIND VECTOR ---     0.
25--DIRECTION FOR SPREAD CALCULATIONS ----     0.  (DIRECTION OF MAX SPREAD)
26--EXPOSURE OF FUELS TO THE WIND --------     1 = EXPOSED
27--BURN TIME CLOUD COVER, % -------------     0.
28--BURN TIME HAZINESS -------------------     1 = VERY CLEAR SKY

29--BURN DAY 1400 TEMPERATURE, F ---------    78.
30--BURN DAY 1400 RELATIVE HUMIDITY, % ---    34.
31--BURN DAY 1400 20-FT WINDSPEED, MI/H --     0.
32--BURN DAY 1400 CLOUD COVER, % ---------     0.
33--BURN DAY 1400 HAZINESS ---------------     1 = VERY CLEAR SKY

42--MOISTURE INITIALIZATION OPTION -------     4 = INCOMPLETE WEATHER DATA
                                                   NO RAIN THE WEEK BEFORE BURN
                                                   WEATHER PATTERN HOLDING

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN
```

```
INTERMEDIATE VALUES

     TIME OF SUNSET-----------------  1822.
     TIME OF SUNRISE----------------   537.
     FUEL SURFACE TEMPERATURE, F----   115.
     FUEL LEVEL RH, %---------------    10.
     PERCENT SHADE------------------     0.
     FINE DEAD FUEL MOISTURE, %-----   4.1
```

Most of the SITE input is used to calculate this.

```
BASIC INPUT

     FUEL MODEL---------------------     1-- SHORT GRASS (1 FT)
     1-HR FUEL MOISTURE, %----------     4.1
     MIDFLAME WINDSPEED, MI/H ------     0.0
     PERCENT SLOPE------------------     0.0
     DIRECTION OF THE WIND VECTOR---     0.0
     DIRECTION OF SPREAD------------     0.0  (DIRECTION OF MAX SPREAD)
      CALCULATIONS
```

The basic input and output are the same as for DIRECT.

```
OUTPUT


     RATE OF SPREAD, CH/H-----------     5.
     HEAT PER UNIT AREA, BTU/SQ.FT--    95.
     FIRELINE INTENSITY, BTU/FT/S---     8.
     FLAME LENGTH, FT---------------     1.2
     REACTION INTENSITY, BTU/SQ.FT/M   870.
     EFFECTIVE WINDSPEED, MI/H------     0.0

IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      SIZE
>INPUT
```

Let's do it again for a situation that requires more input.

```
(1) MONTH OF BURN ? 1-12 OR QUIT
>6

(2) DAY OF BURN ? 1 - 31
>23

(3) DO YOU KNOW THE LATITUDE ? Y-N
>N

(3) TWO-LETTER STATE ABBREVIATION ?
>MT

(3) LATITUDE = 46. DEG

SUNSET  = 1946.
SUNRISE =  413.

(4) BURN TIME ? 0000-2359
>2200
```

Night burn.

```
(5) DO YOU WANT TO USE THE TWO FUEL MODEL CONCEPT ? Y-N
>N

(5) FUEL MODEL ? 1-99
>2

(6) DO YOU KNOW 10-HR FUEL MOISTURE ? Y-N
>N

AN ESTIMATE WILL BE BASED ON THE CALCULATED 1-HR VALUE

(6) WILL 10-HR MOIS. BE WETTER THAN 1-HR MOIS ? Y-N
>Y

(6) WHAT IS THE MOISTURE DIFFERENCE, %(MOIS.) ? 0-20
>2

(7) DO YOU KNOW 100-HR FUEL MOISTURE ? Y-N
>N

AN ESTIMATE WILL BE BASED ON THE CALCULATED 1-HR VALUE

(7) WILL 100-HR MOIS. BE WETTER THAN 1-HR MOIS ? Y-N
>Y

(7) WHAT IS THE MOISTURE DIFFERENCE, %(MOIS.) ? 0-20
>3

(8) DO YOU WANT TO SEE THE LIVE FUEL MOISTURE GUIDELINES ? Y-N
>N

(8) LIVE HERBACEOUS MOIS, % ? 30-300
>120

(10) DO YOU WANT TO ENTER MAP MEASUREMENTS TO
     CALCULATE PERCENT SLOPE ? Y-N
>N

(10) PERCENT SLOPE ? 0-100
>25

(11) ELEVATION OF FIRE LOCATION, FT ? 0-12000
>1200

(12) IS THE ELEVATION DIFFERENCE BETWEEN THE LOCATION OF THE
     FIRE AND THE LOCATION OF THE TEMPERATURE AND HUMIDITY READINGS
     MORE THAN 1000 FT ? Y-N
>Y

(12) IS THE AIR WELL MIXED BETWEEN THE TWO LOCATIONS ? Y-N
>Y

(12) IS THE FIRE SITE AT A HIGHER LOCATION ? Y-N
>1000
1 IS NOT A VALID ANSWER.
TYPE Y FOR YES  OR  N FOR NO.
>1000
1 IS NOT A VALID ANSWER.
TYPE Y FOR YES  OR  N FOR NO.
>Y

(12) WHAT IS THE ELEVATION DIFFERENCE, FT ? 1000-9000
>1000
```

Always read the question!

```
(13) ASPECT ? N,NE,E,SE,S,SW,W,NW
>NE

(14) CROWN CLOSURE, % ? 0-100
       (ENTER THE CLOSURE AS IF THERE WERE FOLIAGE)
>30

(15) IS FOLIAGE PRESENT ? Y-N
>Y

(16) ARE THE TREES IN THIS STAND SHADE TOLERANT ? Y-N
>N

(17) DOMINANT TREE TYPE ? 1-2
       1=CONIFEROUS
       2=DECIDUOUS
>1

(18) AVERAGE TREE HEIGHT, FT ? 10-300
>60

(19) RATIO OF CROWN HEIGHT TO TREE HEIGHT ? .1-1
>.6

(20) RATIO OF CROWN HEIGHT TO CROWN DIAMETER ? .2-5
>3

(21) BURN TIME TEMPERATURE, F ? 33-120 OR QUIT
>88

(22) DO YOU KNOW THE BURN TIME RELATIVE HUMIDITY ? Y-N
>N

(22) IS A FRONTAL PASSAGE OR AN INVERSION EXPECTED
     BETWEEN 1400 AND BURN TIME ? Y-N
>N

(23) BURN TIME 20-FT WINDSPEED, MI/H ? 0-99
>5

(24) BURN TIME DIRECTION OF WIND VECTOR ? 0-360
       (DEGREES CLOCKWISE FROM UPHILL)
>0

(25) DO YOU WANT FIRE BEHAVIOR PREDICTIONS ONLY FOR
     THE DIRECTION OF MAXIMUM SPREAD ? Y-N
>Y

(26) EXPOSURE OF FUELS TO THE WIND ? 0-4
      0=DONT KNOW
      1=EXPOSED
      2=PARTIALLY SHELTERED
      3=FULLY SHELTERED--OPEN STAND
      4=FULLY SHELTERED--DENSE STAND
>0

(26) IS THE FUEL NEAR A CLEARING ? Y-N
>N

(26) IS THE FUEL HIGH ON A RIDGE WHERE TREES OFFER
     LITTLE SHELTER FROM THE WIND ? Y-N
>N
```

The RH estimate will be printed when the input is complete.

Refer to exhibit 2 to understand the logic of the questions for line 26.

```
(26) IS THE FUEL MIDSLOPE OR HIGHER ON A MOUNTAIN
     WITH WIND BLOWING DIRECTLY AT THE SLOPE ? Y-N
>N

(26) IS THIS A PATCHY STAND OF TIMBER ? Y-N
>Y

FUELS ARE PARTIALLY SHELTERED FROM THE WIND

WIND ADJUSTMENT FACTOR = .3

(29) BURN DAY 1400 TEMPERATURE, F ? 33-120
>90

(30) BURN DAY 1400 RELATIVE HUMIDITY, % ? 1-100
>34

(31) BURN DAY 1400 20-FT WINDSPEED, MI/H ? 0-99
>8

(32) BURN DAY 1400 CLOUD COVER, % ? 0-100
>30

(33) BURN DAY 1400 HAZINESS ? 1-4
       1=VERY CLEAR SKY
       2=AVERAGE CLEAR FOREST ATMOSPHERE
       3=MODERATE FOREST BLUE HAZE
       4=DENSE HAZE
>3

(34) SUNSET TEMPERATURE, F ? 33-120
>70

(35) DO YOU KNOW THE SUNSET RELATIVE HUMIDITY ? Y-N
>Y

(35) SUNSET RELATIVE HUMIDITY, % ? 1-100
>45

(36) SUNSET 20-FT WINDSPEED, MI/H ? 0-99
>3

(37) SUNSET CLOUD COVER, % ? 0-100
>0

(42) MOISTURE INITIALIZATION OPTION ? 1-5

       1=FINE FUEL MOISTURE KNOWN FOR BURN DAY -1

       2=COMPLETE WEATHER DATA FOR 3 TO 7 DAYS

       3=INCOMPLETE WEATHER DATA
         RAIN THE WEEK BEFORE THE BURN

       4=INCOMPLETE WEATHER DATA
         NO RAIN THE WEEK BEFORE THE BURN
         WEATHER PATTERN HOLDING
         (NO ADDITIONAL INPUT)

       5=INCOMPLETE WEATHER DATA
         WEATHER PATTERN CHANGING
```

```
(50) NUMBER OF DAYS BEFORE THE BURN THAT RAIN OCCURRED ? 1-7
>4

(51) RAIN AMOUNT, HUNDREDTHS OF AN INCH? 1-400
30
```
= .3 inch

This is necessary because no input value can be entered to more accuracy than tenths.

```
(52) 1400 TEMPERATURE ON THE DAY IT RAINED, F ? 33-120
>56

(53) SKY CONDITION FROM THE DAY IT RAINED TILL BURN DAY ? 1-3
       1=CLEAR
       2=CLOUDY
       3=PARTLY CLOUDY
>3

(22) ESTIMATED BURN TIME RELATIVE HUMIDITY = 36.%
```
← Calculated

```
SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>LIST

 1--MONTH OF BURN -------------------------     6.
 2--DAY OF BURN ---------------------------    23.
 3--LATITUDE, DEG. ------------------------    46.
    STATE ---------------------------------    MT

 4--BURN TIME ----------------------------- 2200.

 5--FUEL MODEL ----------------------------     2.
                                               TIMBER (GRASS AND UNDERSTORY)

 6--10-HR FUEL MOISTURE, % ----------------   10-HR = 1-HR + 2.
 7--100-HR FUEL MOISTURE, % --------------- 100-HR = 1-HR + 3.
 8--LIVE HERBACEOUS MOIS., % --------------   120.

10--SLOPE, % ------------------------------    25.
11--ELEVATION OF FIRE SITE, FT ------------ 1200.
12--ELEVATION DIFFERENCE BETWEEN FIRE------ 1000. -- FIRE SITE AT
      SITE AND SITE OF T/RH READINGS, FT              HIGHER ELEVATION
13--ASPECT --------------------------------    NE

14--CROWN CLOSURE, % ----------------------    30.
15--FOLIAGE -------------------------------    PRESENT
16--SHADE TOLERANCE -----------------------    INTOLERANT
17--DOMINANT TREE TYPE --------------------     1 = CONIFEROUS
18--AVERAGE TREE HEIGHT, FT ---------------    60.
19--RATIO OF CROWN HEIGHT TO
      TREE HEIGHT -------------------------     0.6
20--RATIO OF CROWN HEIGHT TO
      CROWN DIAMETER ----------------------     3.0

21--BURN TIME TEMPERATURE, F --------------    88.
22--BURN TIME RELATIVE HUMIDITY, % --------    36.
23--BURN TIME 20-FT WINDSPEED, MI/H -------     5.
24--BURN TIME DIRECTION OF WIND VECTOR ----     0.
      DEGREES CLOCKWISE FROM UPHILL
25--DIRECTION FOR SPREAD CALCULATIONS -----     0.  (DIRECTION OF MAX SPREAD)
      DEGREES CLOCKWISE FROM UPHILL
26--EXPOSURE OF FUELS TO THE WIND ---------     2 = PARTIALLY SHELTERED
```

```
29--BURN DAY 1400 TEMPERATURE, F ----------    90.
30--BURN DAY 1400 RELATIVE HUMIDITY, % ----    34.
31--BURN DAY 1400 20-FT WINDSPEED, MI/H ---     8.
32--BURN DAY 1400 CLOUD COVER, % ----------    30.
33--BURN DAY 1400 HAZINESS ---------------      3 = MODERATE FOREST BLUE HAZE

34--SUNSET TEMPERATURE, F ----------------     70.
35--SUNSET RELATIVE HUMIDITY, % ----------     45.
36--SUNSET 20-FT WINDSPEED, MI/H ---------      3.
37--SUNSET CLOUD COVER, % ----------------      0.

42--MOISTURE INITIALIZATION OPTION --------     3 = INCOMPLETE WEATHER DATA
                                                    RAIN THE WEEK BEFORE BURN
50--NUMBER OF DAYS BEFORE THE BURN
      THAT RAIN OCCURRED -----------------      4
51--RAIN AMOUNT, HUNDRETHS OF AN INCH -----    30.
52--1400 TEMPERATURE ON THE DAY
      IT RAINED, F -----------------------     56.
53--SKY CONDITION FROM THE DAY IT RAINED
      UNTIL BURN DAY ---------------------      3 = PARTLY CLOUDY

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
>RUN

INTERMEDIATE VALUES

     TIME OF SUNSET----------------  1946.
     TIME OF SUNRISE---------------   413.
     WIND ADJUSTMENT FACTOR---------    0.3
     FUEL SURFACE TEMPERATURE, F----   85.
     FUEL LEVEL RH, %---------------   39.
     PERCENT SHADE------------------  100.
     FINE DEAD FUEL MOISTURE, %-----   10.4


BASIC INPUT

     FUEL MODEL---------------------    2-- TIMBER (GRASS AND UNDERSTORY)
     1-HR FUEL MOISTURE, %----------   10.4
     10-HR FUEL MOISTURE, %---------   12.4
     100-HR FUEL MOISTURE, %--------   13.4
     LIVE HERBACEOUS MOIS, %--------  120.0
     MIDFLAME WINDSPEED, MI/H ------    1.5
     PERCENT SLOPE------------------   25.0
     DIRECTION OF THE WIND VECTOR---    0.0
      DEGREES CLOCKWISE
       FROM UPHILL
     DIRECTION OF SPREAD------------    0.0  (DIRECTION OF MAX SPREAD)
      CALCULATIONS
      DEGREES CLOCKWISE
       FROM UPHILL
```

```
     RATE OF SPREAD, CH/H-----------      7.
     HEAT PER UNIT AREA, BTU/SQ.FT--    404.
     FIRELINE INTENSITY, BTU/FT/S---     51.
     FLAME LENGTH, FT---------------      2.7
     REACTION INTENSITY, BTU/SQ.FT/M  2928.
     EFFECTIVE WINDSPEED, MI/H------      2.2

IF YOU WANT TO CONTINUE WITH THE AREA AND PERIMETER CALCULATIONS,
  TYPE 'SIZE'

SITE KEYWORD?
ENTER INPUT,LIST,CHANGE,RUN,QUIT,
      HELP,KEY,TERSE,WORDY,PAUSE,NOPAUSE
      SIZE
>QUIT

FINISH SITE -- BACK TO FIRE1



FIRE1 KEYWORD?
ENTER DIRECT,SITE,SIZE,CONTAIN,SPOT,DISPATCH,CUSTOM
      KEY,HELP,TERSE,WORDY,PAUSE,NOPAUSE,QUIT
>QUIT


DO YOU  R E A L L Y  WANT TO TERMINATE THIS RUN? Y-N
>Y <-------------------------- YES. I really do.

FIRE1 RUN TERMINATED.
******************************
```

APPENDIX B: INPUT/OUTPUT FORMS AND DESCRIPTIONS OF INPUT VARIABLES

An input/output form is supplied for each module of the FIRE1 program of BEHAVE. In addition, quick reference sheets describe all input variables, noting the valid range for input and whether range input is allowed. This material can be used as a quick reference while running the program.

DIRECT MODULE INPUT/OUTPUT

INPUT

1	Fuel model	____	____	____	____	____
2	1-h fuel moisture, %	____	____	____	____	____
3	* 10-h fuel moisture, %	____	____	____	____	____
4	* 100-h fuel moisture, %	____	____	____	____	____
5	* Live herbaceous moisture, %	____	____	____	____	____
6	* Live woody moisture, %	____	____	____	____	____
7	Midflame windspeed, mi/h	____	____	____	____	____
8	Slope, %	____	____	____	____	____
9	Direction of wind vector, degrees clockwise from uphill	____	____	____	____	____
10	@ Direction for spread calculations, degrees clockwise from uphill (or from the wind vector if slope is zero)	____	____	____	____	____

OUTPUT

1	Rate of spread, ch/h	____	____	____	____	____
2	Heat per unit area, Btu/ft^2	____	____	____	____	____
3	Fireline intensity, Btu/ft/s	____	____	____	____	____
4	Flame length, ft	____	____	____	____	____
5	Reaction intensity, Btu/ft^2/min	____	____	____	____	____
6	Effective windspeed, mi/h	____	____	____	____	____
7	# Direction of maximum spread, degrees clockwise from uphill	____	____	____	____	____

* Input only for fuel models that have this component.
@ Can be input directly or the direction of maximum spread can be calculated.
\# Output only if specified in line 10 that the direction of maximum spread is to be calculated.

SIZE MODULE INPUT/OUTPUT

INPUT

1	* Rate of spread, ch/h					
2	* Effective windspeed, mi/h					
3	Elapsed time, h					

OUTPUT

1	Area, acres					
2	Perimeter, ch					
3	Length-to-width ratio					
4	Forward spread distance, ch					
5	Backing spread distance, ch					
6	Maximum width of fire, ch					

* Input only when SIZE is used as an independent module.

CONTAIN MODULE INPUT/OUTPUT

INPUT

1		Run option (code)					
2		Mode of attack (code)					
3	@	Rate of spread, ch/h					
4	@	Initial fire size, acres					
5	@	Length-to-width ratio					
6	*	Burned area target, acres					
7	#	Line building rate, ch/h					

OUTPUT

1		Total length of line, ch					
2		Containment time, h					
3	*	Line-building rate, ch/h					
3	#	Final fire size, acres					

@ Input only when CONTAIN is used as an independent module.
* Only for run option 1 (calculate line-building rate).
\# Only for run option 2 (calculate final fire size).

DIRECT-SIZE-CONTAIN LINKED INPUT

DIRECT INPUT

1	Fuel model				
2	1-h fuel moisture, %				
3	10-h fuel moisture, %				
4	100-h fuel moisture, %				
5	Live herbaceous moisture, %				
6	Live woody moisture, %				
7	Midflame windspeed, mi/h				
8	Slope, %				
9	Direction of wind vector, degrees clockwise from uphill				
10	Direction for spread calculations, degrees clockwise from uphill (or from the wind vector is slope is zero)				

SIZE INPUT

3	Elapsed time, h				

CONTAIN INPUT

1	Run option (code)				
2	Mode of attack (code)				
6	Burned area target, acres				
	or				
7	Line-building rate, ch/h				

DIRECT-SIZE-CONTAIN LINKED OUTPUT

DIRECT OUTPUT

1	Rate of spread, ch/h				
2	Heat per unit area, Btu/ft^2				
3	Fireline intensity, Btu/ft/s				
4	Flame length, ft				
5	Reaction intensity, Btu/ft^2/min				
6	Effective windspeed, mi/h				
7	Direction of maximum spread, degrees clockwise from uphill				

SIZE OUTPUT

1	Area, acres				
2	Perimeter, ch				
3	Length-to-width ratio				
4	Forward spread distance, ch				
5	Backing spread distance, ch				
6	Maximum width of fire, ch				

CONTAIN OUTPUT

1	Total length of line, ch				
2	Containment time, h				
3	Line-building rate, ch/h				
	or				
3	Final fire size, acres				

SPOT MODULE INPUT/OUTPUT

INPUT

1	Firebrand source (code)					
2	Mean cover height, ft					
3	20-ft windspeed, mi/h					
4	Ridge-to-valley elevation difference, ft					
5	Ridge-to-valley horizontal distance, mi					
6	Spotting source location (code)					
7	* Tree species (code)					
8	* Torching tree d.b.h., inches					
9	* Torching tree height, ft					
10	* Number of trees torching together					
11	# Continuous flame height, ft					

OUTPUT

	Maximum spotting distance, mi					

* Input only for firebrand source = 1 (torching tree option).
# Input only for firebrand source = 2 (pile burning option).

DISPATCH MODULE INPUT/OUTPUT

INPUT						
1	Fuel model					
2	Dead fuel moisture, %					
3	Live fuel moisture, %					
4	20-ft windspeed, mi/h (upslope)					
5	Wind adjustment factor					
6	Slope, %					
7	Elapsed time from ignition to attack, h					
8	Line-building rate, ch/h					
OUTPUT						
	Forward rate of spread, ch/h					
	Heat per unit area, Btu/ft^2					
	Fireline intensity, Btu/ft/s					
	Flame length, ft					
	Area at time of attack, acres					
	Perimeter at time of attack, ch					
Head attack:						
	Total length of line, ch (perimeter of burned area)					
	Elapsed time from attack to containment, h					
	Final fire size, acres					
Rear attack:						
	Total length of line, ch (perimeter of burned area)					
	Elapsed time from attack to containment, h					
	Final fire size, acres					

SITE MODULE INPUT/OUTPUT

TIME AND LOCATION

1	Month of burn	____	1	
2	Day of burn	____	2	
3	Latitude, degrees	____	3	IF latitude is known or
	State	____		IF latitude is not known
4	Burn time (2400 hour)	____	4	

FUEL MODEL

5	Fuel model	____	5	
	Percent cover	____		IF two-fuel-model concept
	Other fuel model	____		

FUEL MOISTURE

6	10-h fuel moisture, %	____	6	IF 10-h fuel in model
7	100-h fuel moisture, %	____	7	IF 100-h fuel in model
8	Live herbaceous moisture, %	____	8	IF herbaceous fuel in model
9	Live woody moisture, %	____	9	IF woody fuel in model

SLOPE, ELEVATION, ASPECT

10	Slope, %	____	10	IF slope is known or
	Map scale (code or representative fraction or inches/mi)	____		
	Contour interval, ft	____		
	Map distance, inches	____		IF slope is not known
	Number of contour intervals	____		
11	Elevation of fire location, ft	____	11	
12	Elevation difference between fire location and T/RH readings, ft	____	12	
13	Aspect	____	13	IF slope > 0

TIMBER OVERSTORY DESCRIPTION

14	Crown closure, %	____	14	
15	Foliage present or absent	____	15	
16	Shade tolerant or intolerant	____	16	
17	Dominant tree type (code)	____	17	IF crown closure > 0
18	Average tree height, ft	____	18	
19	Ratio of crown height to tree height	____	19	
20	Ratio of crown height to crown diameter	____	20	

BURN TIME WEATHER

21	Burn time temperature, °F	______	21	
22	Burn time relative humidity, %	______	22	
23	Burn time 20-ft windspeed, mi/h	______	23	
24	Burn time direction of wind vector, degrees clockwise from uphill	______	24	IF wind > 0
25	Direction for spread calculations, degrees clockwise from uphill or from wind vector if slope = 0 (direction of maximum spread can be calculated)	______	25	
26	Exposure of fuels to the wind (code)	______	26	
27	Burn time cloud cover, %	______	27	IF daytime burn +----+----+----------+----+ 12 16 SS SR 12
28	Burn time haziness (code)	______	28	IF burn time before 1600 or after sunrise +----+----+----------+----+ 12 16 SS SR 12

EARLY AFTERNOON WEATHER

29	Burn day 1400 temperature, °F	______	29	IF burn time **not** between 1200 and 1600 +----+----+----------+----+ 12 16 SS SR 12
30	Burn day 1400 relative humidity, %	______	30	
31	Burn day 1400 20-ft windspeed, mi/h	______	31	
32	Burn day 1400 cloud cover, %	______	32	
33	Burn day 1400 haziness (code)	______	33	

SUNSET WEATHER

34	Sunset temperature, °F	______	34	IF burn time after sunset and before 1200 +----+----+----------+----+ 12 16 SS SR 12
35	Sunset relative humidity, %	______	35	
36	Sunset 20-ft windspeed, mi/h	______	36	
37	Sunset cloud cover, %	______	37	

SUNRISE WEATHER

38	Sunrise temperature, °F	______	38	IF burn time after sunrise and before 1200 +----+----+----------+----+ 12 16 SS SR 12
39	Sunrise relative humidity, %	______	39	
40	Sunrise 20-ft windspeed, mi/h	______	40	
41	Sunrise cloud cover, %	______	41	

MOISTURE INITIALIZATION OPTION

42	Moisture initialization option (code)	________	42

FINE FUEL MOISTURE KNOWN FOR THE DAY BEFORE THE BURN

43	Burn day −1 fine fuel moisture, %	________	43	IF moisture initialization option = 1

COMPLETE WEATHER AVAILABLE FOR 3 TO 7 DAYS PRIOR TO THE BURN

IF moisture initialization option = 2

		−1	−2	−3	−4	−5	−6	−7	
44	Number of days of weather								44
45	Burn day −x 1400 temperature, °F	___	___	___	___	___	___	___	45
46	Burn day −x 1400 relative humidity, %	___	___	___	___	___	___	___	46
47	Burn day −x 1400 20-ft windspeed, mi/h	___	___	___	___	___	___	___	47
48	Burn day −x 1400 cloud cover, %	___	___	___	___	___	___	___	48
49	Burn day −x rain amount, hundredths of an inch	___	___	___	___	___	___	___	49

INCOMPLETE WEATHER DATA; RAIN THE WEEK BEFORE THE BURN

IF moisture initialization option = 3

50	Number of days before the burn that rain occurred	________	50
51	Rain amount, hundredths of an inch	________	51
52	1400 temperature on the day it rained, °F	________	52
53	Sky condition from the day it rained until burn day (code)	________	53

INCOMPLETE WEATHER DATA; NO RAIN THE WEEK BEFORE THE BURN; WEATHER PATTERN HOLDING

No additional input

IF moisture initialization option = 4

INCOMPLETE WEATHER DATA; WEATHER PATTERN CHANGING

IF moisture initialization option = 5

54	Burn day −1 1400 temperature, °F	________	54
55	Burn day −1 1400 relative humidity, %	________	55
56	Burn day −1 1400 20-ft windspeed, mi/h	________	56
57	Burn day −1 1400 cloud cover, %	________	57
58	Weather condition prior to burn day −1 (code)	________	58

INTERMEDIATE VALUES

Time of sunset ______

Time of sunrise ______

Wind adjustment factor ______

Fuel surface temperature, °F ______

Fuel level relative humidity, % ______

Percent shade ______

Fine dead fuel moisture, % ______

BASIC INPUT

Fuel model ______

1-h fuel moisture, % ______

10-h fuel moisture, % ______

100-h fuel moisture, % ______

Live herbaceous fuel moisture, % ______

Live woody fuel moisture, % ______

Midflame windspeed, mi/h ______

Slope, % ______

Direction of wind vector, degrees clockwise from uphill (or from the wind vector if slope is zero) ______

Direction for spread calculations, degrees clockwise from uphill (or from the wind vector if slope is zero) ______

OUTPUT

Rate of spread, ch/h ______

Heat per unit area, Btu/ft^2 ______

Fireline intensity, Btu/ft/s ______

Flame length, ft ______

Reaction intensity, Btu/ft^2/min ______

Effective windspeed, mi/h ______

Direction of maximum spread, degrees clockwise from uphill ______

DIRECT INPUT VARIABLES

Line No.	Value	Legal values	Range OK?	Comments
1	Fuel model	1-99 QUIT	n	1-13 for standard NFFL models. 14-99 for custom models from file. 0 indicates that you want to use the two-fuel-model concept. You will be asked for DOMINANT FUEL MODEL PERCENT COVER OTHER FUEL MODEL. Can type QUIT to terminate DIRECT input.
2	1-h fuel moisture, %	1-60	y	Required input. All fuel models have 1-h fuels.
3	10-h fuel moisture, %	1-60	y	Input only for fuel models that have 10-h fuels.
4	100-h fuel moisture, %	1-60	y	Input only for fuel models that have 100-h fuels.
5	Live herbaceous moisture, %	30-300	y	Input only for fuel models that have live herbaceous fuels. The input value is used to determine the amount of fuel load that is transferred from the live herbaceous class to the 1-h dead class for **dynamic** custom fuel models.
6	Live woody moisture, %	30-300	y	Input only for fuel models that have live woody fuel.
7	Midflame windspeed, mi/h	0-99	y	
8	Slope, %	0-100	y	
9	Direction of the wind vector, degrees	0-360	y	Wind direction is specified as degrees clockwise from upslope. This is the direction that the wind is blowing **to,** the direction that the wind is pushing the fire. Enter 0 if the wind is blowing directly upslope. If slope = 0 or windspeed = 0, the question is not asked, and wind direction is set to 0.
10	Direction for the spread calculations, degrees	0-360	y	You will be asked if you want predictions only for the direction of maximum spread. If you answer **yes**, spread direction is not requested. If windspeed, slope, and wind direction are all nonzero values, the direction of maximum spread will be calculated. Otherwise, the direction of maximum spread is 0. If you answer **no**, spread direction is requested. Spread direction is specified as degrees clockwise from upslope unless there is no slope; then it is specified as degrees clockwise from the wind vector.

SIZE INPUT VARIABLES

Line No.	Value	Legal values	Range OK?	Comments
1	Rate of spread, ch/h	0.1-500 QUIT	y	Forward rate of spread. This is a user input if SIZE is used as an independent module. If SIZE is linked to DIRECT or SITE, then the calculated rate of spread is used. Can type QUIT to terminate SIZE input.
2	Effective windspeed, mi/h	0-99	y	Effective windspeed accounts for the combined effects of slope and midflame windspeed. This is a user input if SIZE is used as an independent module. If SIZE is linked to DIRECT or SITE, then the calculated effective windspeed is used.
3	Elapsed time, h	0.5-8	y	This is the elapsed time from ignition. During this time period, conditions are assumed to be uniform.

CONTAIN INPUT VARIABLES

Line No.	Value	Legal values	Range OK?	Comments
1	Run option	1-2 QUIT	n	Code input: 1 = compute line construction rate 2 = compute burned area Can type QUIT to terminate CONTAIN input.
2	Mode of attack	1-2	n	Code input: 1 = head 2 = rear
3	Rate of spread, ch/h	0.1-500	y	Forward rate of spread. If CONTAIN is used as an independent module, this is a direct input. If CONTAIN is linked to DIRECT or SITE and SIZE, then the calculated rate of spread is used as input to CONTAIN.
4	Initial fire size, acres	0.1-100	y	The fire shape at this time should be roughly elliptical. If CONTAIN is used as an independent module, then this is a direct input. If CONTAIN is linked to DIRECT or SITE and SIZE, the calculated area is used as input to CONTAIN.
5	Length-to-width ratio	1-7	y	This describes the shape of the elliptical fire. If CONTAIN is used as an independent module, then this is a direct input. If CONTAIN is linked to DIRECT or SITE and SIZE, then the calculated length-to-width ratio is used as input to CONTAIN.
6	Burned area target, acres	0.1-2000	y	Input only for run option 1. The target area at containment. The required line-building rate is calculated.
7	Line-building rate, ch/h	0.1-200	y	Input only for run option 2. Use total line-building rate for fire. The final fire size is calculated.

SPOT INPUT VARIABLES

Line No.	Value	Legal values	Range OK?	Comments
1	Firebrand source	1-2 QUIT	n	Code input: 1 = torching tree 2 = burning pile 3 = wind-driven surface fire (not yet in the program) 4 = running crown fire (We can't do this. This is in the list to emphasize that a running crown fire differs from torching trees.) Can type QUIT to terminate SPOT input.
2	Mean cover height, ft	0-300	y	For open cover, divide average tree height by 2. Enter 0 for short grass, bare ground, or water.
3	20-ft windspeed, mi/h	0-99	y	20 ft above the treetops.
4	Ridge/valley elevation difference, ft	0-4000	y	Used as multiples of 1000 in the calculations.
5	Ridge/valley horizontal distance, mi	0-4	y	Map distance.
6	Spotting source location	0-3	n	Code input: 0 = midslope, windward side 1 = valley bottom 2 = midslope, leeward side 3 = ridgetop
7	Tree species	1-6	n	Input only for torching tree option. Code input: 1 = Engelmann spruce 2 = Douglas-fir, subalpine fir 3 = hemlock 4 = ponderosa pine, lodgepole pine 5 = white pine 6 = balsam fir, grand fir
8	Torching tree d.b.h., inches	5-40	y	Input only for torching tree option.
9	Torching tree height, ft	10-300	y	Input only for torching tree option.
10	Number of trees torching	1-30	y	Input only for torching tree option.
11	Continuous flame height, ft	1-100	y	Input only for pile burning option.

DISPATCH INPUT VARIABLES*

Line No.	Value	Legal values	Comments
1	Fuel model	1-99 QUIT	1-13 for standard fuel models. 14-99 for custom fuel models. Two-fuel-model concept not allowed. Can type QUIT to terminate DISPATCH input.
2	Dead fuel moisture, %	1-60	1-h, 10-h, and 100-h fuels are all assigned the same fuel moisture.
3	Live fuel moisture, %	30-300	Live herbaceous and live woody fuel are assigned the same fuel moisture. This input is always requested, whether or not there are live fuels in the fuel model being used.
4	20-ft windspeed, mi/h	0-99	Windspeeds are generally forecast for the 20-ft level. Wind is assumed to be blowing uphill.
5	Wind adjustment factor	0.1-1	This value can be looked up on a table. Exposure to the wind depends on canopy cover, topography, and possibly fuel model.
6	Percent slope	0-100	
7	Elapsed time from ignition to attack, hours	0.1-8	The fire should be spreading steadily during this time. This does not include the time that an ignition smolders before it "takes off."
8	Line-building rate, ch/h	0.1-200	Use total line-building rate for the fire. The final fire size is calculated for both head and rear attack.

*Ranges are not allowed for any input value.

SITE INPUT VARIABLES*

Line No.	Value	Legal values	Comments
1	Month of year	1-12 QUIT	Can type QUIT to terminate SITE input.
2	Day of burn	1-31	No error checking for the maximum number of days in each month.
3	Latitude, degrees State	0-90	You will be asked if you know the latitude. If Y, input value. If N, enter 2-letter State abbreviation and average latitude for State will be assigned.
4	Burn time (2400-hour)	0-2359	This is solar time.
5	Fuel model	1-99	1-13 for standard NFFL models. 14-99 for custom models from file. 0 indicates that you want to use the two-fuel-model concept. You will be asked for DOMINANT FUEL MODEL PERCENT COVER OTHER FUEL MODEL.
6	10-h fuel moisture, %	1-60	Input only for fuel models that have 10-h fuels. If value is not known, it will be estimated for you. You must tell whether it will be wetter or drier than the 1-h moisture and by what percentage.
7	100-h fuel moisture, %	1-60	Input only for fuel models that have 100-h fuels. If value is not known, it will be estimated for you. You must tell whether it will be wetter or drier than the 1-h moisture and by what percentage.
8	Live herbaceous moisture, %	30-300	Input only for fuel models that have live herbaceous fuels. The input value is used to determine the amount of fuel load that is transferred from the live herbaceous class to the 1-h dead class for **dynamic** custom fuel models.
9	Live woody moisture, %	30-300	Input only for fuel models that have live woody fuel.
10	Slope, %	0-100	Input value if slope is known.
	Map scale	0-8	Slope not known, code input for map scale:

Representative fraction	Inches/mi
0 = direct entry	
1 = 1:253,440	1/4
2 = 1:126,720	1/2
3 = 1:63,360	1
4 = 1:31,680	2
5 = 1:24,000	2.64
6 = 1:21,120	3
7 = 1:15,840	4
8 = 1:7,920	8

If direct entry, choose representative fraction or inches per mile as method of entry and input value.

Line No.	Value	Legal values	Comments
	Contour interval, ft	10-500	Vertical distance between contour intervals on a contour map.
	Map distance, inches	0.1-10	Horizontal measurement between the two designated points where slope is to be calculated.
	Number of contour intervals	1-100	Number of contour intervals between the two designated points where slope is to be calculated.

*Ranges are not allowed for any input variable.

SITE INPUT VARIABLES (CON.)

Line No.	Value	Legal values	Comments
11	Elevation of fire location, ft	0-12000	
12	Elevation difference between fire and T/RH readings more than 1,000 ft?	Y-N	Used to adjust T/RH readings from elevation of reading to elevation of fire. Adjustment can be made only if air is well-mixed between the two locations (no inversions).
	Elevation difference, ft	1000-9000	You must tell if the fire site is at higher location and how much difference there is.
13	Aspect	N,NE,E,SE, S,SW,W,NW,	Input only if slope is greater than zero.
14	Crown closure, %	0-100	Enter as if there were foliage. Lines 15 through 20 are input only if crown closure is greater than zero.
15	Foliage present?	Y-N	
16	Shade tolerant?	Y-N	Are the trees in the overstory shade tolerant or not?
17	Dominant tree type	1-2	Code input: 1 = Coniferous 2 = Deciduous
18	Average tree height, ft	10-300	
19	Ratio of crown height to tree height	0.1-1	
20	Ratio of crown height to crown diameter	0.2-5	
21	Burn time air temperature, °F	33-120 QUIT	Can type QUIT to terminate SITE input.
22	Burn time relative humidity, %	1-100	If you don't know the value and burn time is before 1200 or after 1600, relative humidity can be estimated for you. An estimate can be made only if no frontal passage or inversion is expected between 1400 and burn time. If burn time is between 1200 and 1600, a value must be entered.
23	Burn time 20-ft wind, mi/h	0-99	
24	Burn time direction of wind vector, degrees	0-360	Wind direction is specified as degrees clockwise from upslope. This is the direction that the wind is blowing **to**, the direction that the wind is pushing the fire. Enter 0 if the wind is blowing directly upslope. If slope = 0 or windspeed = 0, the question is not asked.
25	Direction for spread calculations, degrees	0-360	You will be asked if you want predictions only for the direction of maximum spread. If you answer **yes**, spread direction is not requested. If windspeed, slope, and wind direction are all nonzero values, the direction of maximum spread will be calculated. Otherwise, the direction of maximum spread is 0. If you answer **no**, spread direction is requested. Spread direction is specified as degrees clockwise from upslope unless there is no slope; then it is specified as degrees clockwise from the wind vector.

Line No.	Value	Legal values	Comments
26	Exposure of fuels to wind	0-4	Code input: 0 = don't know 1 = exposed 2 = partially sheltered 3 = fully sheltered—open stand 4 = fully sheltered—closed stand If you answer 0, you will be asked a series of questions to help determine exposure. The wind adjustment factor is printed with the intermediate variables.
27	Burn time cloud cover, %	0-100	Required input for daytime burns.
28	Burn time haziness	1-4	Required if burn time before 1600 or after sunrise. Code input: 1 = very clear sky 2 = average clear forest atmosphere 3 = moderate forest blue haze 4 = dense haze or light to moderate smoke Dense smoke should be treated as 100% **cloud cover.**
	Early Afternoon Weather		Questions 29-33 are required if burn time is **not** 1200-1600. If burn time is between 1200 and 1600, 1400 conditions are assumed to be the same as burn time conditions.
29	Burn day 1400 temperature, °F	33-120	
30	Burn day 1400 relative humidity, %	1-100	Cannot be estimated.
31	Burn day 1400 20-ft windspeed, mi/h	0-99	
32	Burn day 1400 cloud cover, %	0-100	
33	Burn day 1400 haziness	1-4	Code input: 1 = very clear sky 2 = average clear forest atmosphere 3 = moderate forest blue haze 4 = dense haze or light to moderate smoke Dense smoke should be treated as 100% cloud cover.
	Sunset Weather		Questions 34-37 are required if burn time is between sunset and 1200 noon.
34	Sunset temperature, °F	33-120	
35	Sunset relative humidity, %	1-100	Can be estimated if no frontal passage or inversion is expected between 1400 and sunset.
36	Sunset 20-ft windspeed, mi/h	0-99	
37	Sunset cloud cover, %	0-100	
	Sunrise Weather		Questions 38-41 are required if burn time is between sunrise and 1200 noon.
38	Sunrise temperature, °F	33-120	
39	Sunrise relative humidity, %	1-100	Can be estimated if no frontal passage or inversion is expected between 1400 and sunrise.
40	Sunrise 20-ft windspeed, mi/h	0-99	
41	Sunrise cloud cover, %	0-100	

Line No.	Value	Legal values	Comments
42	Moisture initialization option	1-5	Code input: 1 = fine fuel moisture known the day before the burn. 2 = complete weather available for 3 to 7 days prior to the burn. 3 = incomplete weather data and it rained the week before the burn. 4 = incomplete weather data, no rain the week before the burn, and weather pattern is stable (no additional input). 5 = incomplete weather data; weather pattern changing.
	Fine Fuel Moisture Known for the Day Before the Burn		
43	Burn day −1 fine fuel moisture, %	1-100	Required for initialization **option 1**.
	Complete Weather Available for 3 to 7 Days Prior to the Burn		
			Questions 44-49 required for initialization **option 2**.
44	No. days of weather data	3-7	
45	Burn day −x 1400 temperature, °F	33-120	Lines 45 through 49 are input for the number of days specified in line 44. x indicates the number of days prior to burn day.
46	Burn day −x 1400 relative humidity, %	1-100	
47	Burn day −x 1400 20-ft windspeed, mi/h	0-99	
48	Burn day −x 1400 cloud cover, %	0-100	
49	Burn day −x rain amount, hundredths of an inch	0-400	
	Incomplete Weather Data; Rain the Week Before the Burn		
			Questions 50-53 required for initialization **option 3**
50	No. days before burn that rain occurred	1-7	
51	Rain amount, hundredths of an inch	0-400	
52	1400 temperature on the day it rained, °F	33-120	
53	Sky condition from the day it rained until burn day	1-3	Code input: 1 = clear 2 = cloudy 3 = partly cloudy
	Incomplete Weather Data; No Rain the Week Before the Burn; Weather Pattern Holding		
			No additional input is required for initialization **option 4**.

Line No.	Value	Legal values	Comments
	Incomplete Weather Data; Weather Pattern Changing		Questions 54-58 required for initialization **option 5.**
54	Burn day −1 1400 temperature, °F	33-120	
55	Burn day −1 1400 relative humidity, %	1-100	
56	Burn day −1 1400 20-ft windspeed, mi/h	0-99	
57	Burn day −1 1400 cloud cover, %	0-100	
58	Weather condition prior to burn day −1	1-3	Code input: 1 = hot and dry 2 = cool and wet 3 = between 1 and 2

SITE INTERMEDIATE VARIABLES

Value	Legal values	Comments
Time of sunset	Calculated	Local sun time. Program won't run unless sunset is after 1600.
Time of sunrise	Calculated	Local sun time.
Wind adjustment factor	Calculated	Based on exposure to the wind (line 26).
Fuel surface temperature, °F	Calculated	Burn time temperature and relative humidity are adjusted for solar radiation and converted to fuel level.
Fuel level relative humidity, %	Calculated	
Percent shade	Calculated	From cloud cover and canopy cover (not haze).
Fine dead fuel moisture, %	Calculated	1-h fuel moisture. Most of the SITE input variables are used to calculate this value.

APPENDIX C: FUEL MODEL FILES

The only aspect of BEHAVE that requires specific understanding of how a computer works is that of fuel model files. This appendix describes the fuel model file and how it is used. This appendix also explains the terminology associated with fuel model files: file name, file description, password, fuel model name, fuel model parameters.

The link among the BEHAVE programs is the fuel model file as illustrated in figure 2. The file is an area in the computer where custom fuel models are stored. A number of fuel models will be stored in a single file. Each user can have one or more personal files, or a file can be accessed by many users. The "Fuel Model File Record" and "Fuel Model Parameter Record" sheets in exhibits 23 and 24 are designed to help you record information about your fuel model files. Refer to the examples in exhibits 25 and 26 for the following discussion.

You assign the file name (for example, ANDREWS.DAT) at the time the file is created by either the NEWMDL or TSTMDL program. The computer uses this name to define a location in its memory. You must specify the name of the file before you use a custom fuel model or add another fuel model to the file.

The name that you assign to your fuel model file depends on the computer that you are using. A file name that is valid on one computer may not be on another. For example, ANDREWS.DAT is valid on the Intermountain Fire Sciences Laboratory's minicomputer, but will cause an unrecoverable fatal error on the Fort Collins Computer Center (FCCC) computer. The BEHAVE programs allow up to 12 characters for a file name and do not check for validity. It is up to you to name your files properly. Check with your computer specialist for clarification. As an example, exhibit 27 illustrates conventions for (naming files for) the FCCC Univac 1100.

You can use up to 72 characters for the **file description** (for example, EXAMPLE FOR APPENDIX C). This is for reference and means nothing to the computer. You type in the description when you create a file. The description is printed when you use the file. The file description helps you keep track of which file you are using. You also assign a four-character **password** (for example, LOOK) at the time the file is created. The password must be typed in when the file is changed. Telling other BEHAVE users your file name, but not the password, allows them to use your custom fuel models without being able to change the file. The password has no meaning to FIRE1 because files can never be changed by that program.

The numbers that define a fuel model are the **fuel model parameters** as seen in exhibit 26 (1 HR LOAD = 2.00 T/A, DEPTH = 1.0 FT, etc.). These values are stored in the file along with a user-assigned fuel model number and name. Wind adjustment factor is included with the fuel model parameters because it is a constant that is fuel model-dependent.

The **fuel model number** can be anything from 14 to 99. The numbers 1 through 13 are reserved for the standard NFFL fuel models. Because you must specify the name of the file before you use a custom fuel model, there is no problem if many users have a fuel model 14, for example.

You assign a 32-character **fuel model name** for your own reference (for example, the name of fuel model 1 is SHORT GRASS; the name of your fuel model 27 might be STRAWBERRY RIDGE).

FUEL MODEL FILE RECORD

FILE NAME ______________________________ PASSWORD ______________

(FCCC qualifier) ______________________

FILE DESCRIPTION ____

FUEL MODELS:

NUMBER	NAME
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________
______	______________________________

Exhibit 23.—Fuel model file form for duplication.

FUEL MODEL PARAMETER RECORD

FILE NAME ____________________

FUEL MODEL NUMBER __________ NAME ____________________

STATIC ______
DYNAMIC ______

LOAD (T/AC)		S/V RATIOS		OTHER	
1 HR	______	1 HR	______	DEPTH (FT)	______
10 HR	______	LIVE HERB	______	HEAT CONTENT (BTU/LB)	______
100 HR	______	LIVE WOODY	______		
LIVE HERB	______	S/V = (SQFT/CUFT)		EXT MOISTURE (%)	______
LIVE WOODY	______				

WIND ADJUSTMENT FACTOR FOR FULLY EXPOSED FUELS ______

FUEL MODEL NUMBER __________ NAME ____________________

STATIC ______
DYNAMIC ______

LOAD (T/AC)		S/V RATIOS		OTHER	
1 HR	______	1 HR	______	DEPTH (FT)	______
10 HR	______	LIVE HERB	______	HEAT CONTENT (BTU/LB)	______
100 HR	______	LIVE WOODY	______		
LIVE HERB	______	S/V = (SQFT/CUFT)		EXT MOISTURE (%)	______
LIVE WOODY	______				

WIND ADJUSTMENT FACTOR FOR FULLY EXPOSED FUELS ______

Exhibit 24.—Fuel model parameter form for duplication.

FUEL MODEL FILE RECORD

FILE NAME ANDREWS.DAT PASSWORD LOOK

(FCCC qualifier) -

FILE DESCRIPTION EXAMPLE FOR APPENDIX C

FUEL MODELS:

NUMBER	NAME
14	SHORT GRASS / LITTER
89	2-YR SLASH/BRUSH
27	STRAWBERRY RIDGE

Exhibit 25.—Example, fuel model file record.

FUEL MODEL PARAMETER RECORD

FILE NAME ANDREWS.DAT

FUEL MODEL NUMBER 27 NAME STRAWBERRY RIDGE

STATIC ____
DYNAMIC ✓

LOAD (T/AC)		S/V RATIOS		OTHER	
1 HR	2.00	1 HR	3000	DEPTH (FT)	1.0
10 HR	1.00	LIVE HERB	1500	HEAT CONTENT (BTU/LB)	8000
100 HR	.50	LIVE WOODY	–		
LIVE HERB	.50	S/V = (SQFT/CUFT)		EXT MOISTURE (%)	25
LIVE WOODY	0				

WIND ADJUSTMENT FACTOR FOR FULLY EXPOSED FUELS .4

FUEL MODEL NUMBER ____ NAME ____

STATIC ____
DYNAMIC ____

LOAD (T/AC)		S/V RATIOS		OTHER	
1 HR		1 HR		DEPTH (FT)	
10 HR		LIVE HERB		HEAT CONTENT (BTU/LB)	
100 HR		LIVE WOODY			
LIVE HERB		S/V = (SQFT/CUFT)		EXT MOISTURE (%)	
LIVE WOODY					

WIND ADJUSTMENT FACTOR FOR FULLY EXPOSED FUELS ____

Exhibit 26.—Example, fuel model (parameter) record.

You can enter a file name up to 12 characters, but don't use the special characters "." or "". The qualifier, which is part of the RUN command (@RUN run-name,account-number,qualifier), is automatically used as part of the file name (qualifier*file-name). But* ***don't*** *type the qualifier when the program asks for the file name.*

Since the files that you create will be public (accessible to anyone), we suggest that you use a qualifier other than BEHAVE to lessen the chance for duplicate file names. If you do pick a name that someone else is already using, you will not be able to alter their file without knowing the password. Just pick another file name.

If you use a different qualifier when you want to use a file than you did when you created the file, you will get a "FILE DOES NOT EXIST" or a "THIS IS A NEW FILE" message even if you typed the file name the same both times. You should decide on a qualifier and stick to it.

Exhibit 27.—Comments on fuel model file naming conventions for the Fort Collins Computer Center (FCCC) Univac 1100.

The format of the fuel model file is given in exhibit 28. The letter "A" is written in the file to indicate that the format is for the 1984 version of BEHAVE. If the format is changed for future updates of the system, the letter will change. It is possible that prediction models added to BEHAVE will require constants to be stored for each fuel model.

"Header" Record

Column(s)	Read format	Data recorded
1 - 4	A4	Password
5 - 6	2X	Blank
7 - 78	18A4	File description
79	1X	Blank
80	A1	A = format indicator

Fuel Model Records

Column(s)	Read format	Data recorded
1 - 2	I2	Fuel model number
3	F1.1	Wind reduction factor
4 - 35	8A4	Fuel model name
36 - 39	F4.2	1-h load
40 - 43	F4.2	10-h load
44 - 47	F4.2	100-h load
48 - 51	F4.2	Live herbaceous load
52 - 55	F4.2	Live woody load
56 - 59	F4.2	Fuel bed depth
60 - 64	F5.0	Heat content
65 - 66	F2.0	Extinction moisture
67 - 70	F4.0	1-h S/V ratio
71 - 74	F4.0	Live herbaceous S/V ratio
75 - 78	F4.0	Live woody S/V ratio
79	A1	A = format indicator
80	I1	0 = static 1 = dynamic

Exhibit 28.—Fuel model file structure.

Fuel model files are created using the NEWMDL and TSTMDL programs of the FUEL subsystem of BEHAVE (Burgan and Rothermel 1984). Fuel models can be added to, deleted from, or replaced in a file using the NEWMDL and TSTMDL programs. Fuel models can be drawn from a file using the TSTMDL and FIRE1 programs. It is important to note that the only interaction that the FIRE1 program has with a file is getting a fuel model from the file.

The FIRE1 keyword CUSTOM allows you to specify the name of the file that you want to access. You can then list the numbers and names of the fuel models in the file or look at the parameters for a specific model. Once a fuel model file is attached to a FIRE1 run using CUSTOM, you can reference its models by number just like the standard 13. You cannot change the file (add, delete, or replace models) or change the parameters of a fuel model using the FIRE1 program.

Fuel models are "built" using the programs NEWMDL and TSTMDL. The keyword MODEL in NEWMDL and FUEL followed by LIST in TSTMDL allow you to see the current parameters for the fuel model that you are working on. These parameters are in "working" memory and will "go away" when you terminate the run unless you use the keyword FILE to save your fuel model in the fuel model file.

When a fuel model is loaded from a file by TSTMDL, it is still in the file and the parameters are also in working memory where they can be changed. You can then use the keyword FILE to replace the original fuel model in the file with the revised model. Or you can RENUMBER the fuel model and then add it to the file as a new fuel model.

TSTMDL also allows you to load an NFFL fuel model into working memory as a custom model. You can change the parameters and FILE it for later use as a custom model.

Only one fuel model can be in working memory at a time. A replacement is made, either by using the keyword FUEL followed by NEW or NFFL or by using the keyword FILE to load a fuel model from the file. When a fuel model is loaded, the one that was previously in the working area is lost unless you saved it in a file.

APPENDIX D: BEHAVE AND THE NATIONAL FIRE-DANGER RATING SYSTEM

Special attention is given to the National Fire-Danger Rating System (NFDRS) (Deeming and others 1977) because it is a widely used national system and because the relative application of NFDRS and BEHAVE is sometimes confused. NFDRS and BEHAVE are both used to evaluate fire potential, but in different ways. They are complementary systems, each with its own niche in fire management applications. NFDRS utilizes standardized weather observations to produce indexes of seasonal fire danger. BEHAVE is for making site-specific fire behavior predictions, with the resolution of the input based on the application. Both BEHAVE and NFDRS are flexible, and can be adapted to a wide range of fire management needs. Proper application depends on the user understanding some of the basic principles of the two systems.

NFDRS became a national system in 1972 and was revised in 1978. Although nomograms for fire behavior calculations were made available in 1976, there were no guidelines for determining input and interpreting output. The nomograms alone are not a fire behavior prediction "system." A manual system for predicting fire behavior evolved through the FBO course and is now published as "How to Predict the Spread and Intensity of Forest and Range Fires" (Rothermel 1983) 11 years after the NFDRS was adopted. Because NFDRS was available before a formal fire behavior prediction system existed, fire danger indexes were sometimes used as specific estimators of fire behavior. This misuse of the NFDRS is understandable, but it has led to confusion regarding the difference between fire danger rating and fire behavior prediction. The availability of BEHAVE as a national fire behavior prediction system should eliminate the problem.

In order to describe the difference between NFDRS and BEHAVE, I will discuss the resolution of the input values, differences in the equations used in the calculations, and interpretation of the output. This is followed by a discussion of fuel models.

Input

Although both NFDRS and BEHAVE ultimately need a fuel model, fuel moisture, windspeed, and slope to estimate fire behavior, the way this input is obtained is quite different. NFDRS requires that standard weather observations be taken once each day. Calculation of daily fire danger indexes is based on this weather, calculated values from previous days, and fixed descriptors of the fire danger area. Often, only a single fuel model and slope class are used to describe a large area. Fuel moistures are calculated from the measured weather. This seasonal calculation of fuel moisture is one of the prime features of NFDRS, allowing it to be an indicator of fire danger.

On the other hand, determination of input values to BEHAVE can vary with the information that is available. For example, you can select one of the 13 NFFL models, a custom model, or the two-fuel-model concept. And fine dead fuel moisture can be entered directly based on a guess or on a measurement in the field, or it can be calculated from the moisture model in SITE. The burden is on the user to make the decision, matching the resolution of BEHAVE input to the application.

Calculations

Both BEHAVE and NFDRS are based on the same mathematical model (Rothermel 1972). Nevertheless, the equations were significantly modified as they are used in the NFDRS (Andrews and Morris in preparation). The adjustments were intended to make the NFDRS indexes better reflect the seasonal

trend. The original model, with modifications by Albini (1976b), is used in BEHAVE and other fire behavior processors. This mathematical model, with additional minor modifications, is also used to calculate Spread Component (SC) in NFDRS. The equations used for Energy Release Component (ERC) are similar to those used in BEHAVE for heat per unit area. However, there is a major difference. To focus more attention on heavy fuels and thus seasonal drying and wetting trends, the weighting is done by loading rather than surface-area-to-volume ratio. Therefore, although ERC and heat per unit area are related, there is a significant difference in their calculation.

In BEHAVE, flame length is calculated from rate of spread and heat per unit area. Correspondingly in NFDRS, Burning Index (BI) is calculated from SC and ERC. Therefore BI is related to flame length, but because of the differences in the calculations they are not the same. It has been said that Burning Index is equal to 10 times the flame length because the 20 NFDRS fuel models were designed to make it so, not because the equations for BI are the same as those used to calculate flame length in BEHAVE. There is a relationship, not an equality. The NFDRS Burning Index is an **index** that rates fire danger (**related to** potential flame length). BEHAVE produces flame length predictions.

Output

NFDRS indexes and components are relative measures of fire potential. Therefore to be meaningful they have to be related to something, usually values from earlier in the season or from previous seasons. This is why proper use of NFDRS depends so heavily on archived weather data. The fire danger class is the bottom line for most applications of NFDRS. These values are based on an analysis of indexes calculated using historical weather.

If there are changes in the NFDRS, all historical calculations must be redone. The impact on users, in both time and money, means that changes are made to NFDRS only when the improvements make the tradeoff worthwhile. Consistency is of primary concern. On the other hand, BEHAVE can more easily be updated as new research becomes available.

The systems are designed quite differently because of their level of application. NFDRS has rigid rules on collecting and entering weather data to make daily calculations. BEHAVE is more flexible and can be used in a variety of ways. Interpretation of results is vital to both NFDRS and BEHAVE.

Application of NFDRS and BEHAVE

NFDRS finds its niche in fire management in broad area planning where seasonal trends and year-to-year comparisons are necessary. NFDRS is well suited for **planned** fire management actions: presuppression, suppression, detection, and prevention. BEHAVE is used for site-specific fire behavior predictions where estimates of actual fire behavior are needed. For example, NFDRS indexes might be used in deciding whether a newly reported fire will be declared a wildfire or a prescribed fire. And for a wildfire, a confine, contain, or control decision might be based on either NFDRS or fire behavior predictions. Fire behavior predictions, however, should be used for projecting the growth of the fire.

Fuel Models

NFDRS utilizes a set of 20 standard fuel models; BEHAVE has a different set of 13 standard (NFFL) fuel models. This situation occurred because the equations that use the fuel models are different for NFDRS and BEHAVE.

A fuel model is a **model**. It is a list of numbers that represent the fuel for a set of equations. Therefore, designing a fuel model involves much more than doing a fuel inventory. It is an iterative process that requires using a fuel

model with the equations to obtain fire behavior predictions, comparing predictions to observed or expected fire behavior, adjusting the fuel model parameters, and so on. If the equations are different (as are those for NFDRS and BEHAVE), then the final fuel model will necessarily be different. Therefore a fuel model is a direct function of the equations that use it. Fuel models for both BEHAVE and NFDRS are designed using the same process. The 20 NFDRS fuel models were designed as part of a research project. Half of the BEHAVE system is devoted to helping users design their own fire behavior fuel models (Burgan and Rothermel 1984). The question is not "which is the 'right' **fuel model**?" but rather "which **system** is best suited to the job at hand?"

Anderson (1982) presented a "Physical Description Similarity Chart of NFDRS and FBO Fuel Models." He gives a correspondence between the 20 NFDRS fuel models and the 13 NFFL fire behavior fuel models (fig. 21). The correlation is primarily based on physical description of the fuel, as indicated by the title of the chart. The two sets of fuel models were correlated by rankings of rate of spread and intensity. The actual calculated values differed. In addition, the correlations were based on severe burning conditions. The correspondence at less severe levels would likely be quite different.

Do not substitute a similar NFFL fuel model for a familiar NFDRS fuel model or use NFDRS fuel models in BEHAVE. To disabuse you of this idea, I will show what happens when one uses NFDRS fuel models in fire behavior calculations (BEHAVE). I will also compare "similar" NFDRS and NFFL fuel models.

To make these comparisons, we must convert Spread Component (SC) to rate of spread, Energy Release Component (ERC) to heat per unit area, and Burning Index (BI) to flame length. Because SC is in ft/min, it is divided by 1.1 to get rate of spread in ch/h. ERC is multiplied by 25 to get heat per unit area (Btu/ft^2). BI is divided by 10 to get flame length (ft) (Deeming and others, 1977, p. 1). This conversion is done only for purposes of illustration. As stated earlier, the basic equations in NFDRS and BEHAVE are different.

PHYSICAL DESCRIPTION SIMILARITY CHART OF NFDRS AND FBO FUEL MODELS

NFDRS MODELS REALINED TO FUELS CONTROLLING SPREAD UNDER SEVERE BURNING CONDITIONS

NFDRS FUEL MODELS	FIRE BEHAVIOR FUEL MODELS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
A W. ANNUALS	X													GRASS
L W. PERENNIAL	X													GRASS
S TUNDRA	X					3rd			2nd					GRASS
C OPEN PINE W/GRASS		X							2nd					GRASS
T SAGEBRUSH W/GRASS		X			3rd	2nd								GRASS
N SAWGRASS			X											GRASS
B MATURE BRUSH (6FT)				X										SHRUB
O HIGH POCOSIN				X										SHRUB
F INTER. BRUSH					2nd	X								SHRUB
Q ALASKA BLACK SPRUCE						X	2nd							SHRUB
D SOUTHERN ROUGH						2nd	X							SHRUB
H SRT- NDL CLSD. NORMAL DEAD								X						TIMBER
R HRWD. LITTER (SUMMER)								X						TIMBER
U W. LONG- NDL PINE									X					TIMBER
P SOUTH, LONG- NDL PINE									X					TIMBER
E HRWD. LITTER (FALL)									X					TIMBER
G SRT- NDL CLSD. HEAVY DEAD										X				TIMBER
K LIGHT SLASH											X			SLASH
J MED. SLASH												X		SLASH
I HEAVY SLASH													X	SLASH
	GRASS			SHRUB				TIMBER			SLASH			

Figure 21.—Similarity chart to align physical descriptions of fire-danger rating fuel models with fire behavior fuel models (from Anderson 1982).

Having made the conversion, table 4 shows rate of spread, heat per unit area, and flame length for three NFDRS fuel models and their "similar" NFFL fuel models. These points are plotted on the fire characteristics chart in figure 22. All calculations use the same environmental conditions: dead fuel moisture, 5 percent; live fuel moisture, 30.3 percent (that is, live herbaceous fuels 99.7 percent cured as used by Anderson, 1982, p. 17); midflame windspeed, 5 mi/h; slope, 33 percent (slope class 2). The NFDRS calculations were done using the direct moisture input option of the NFDRS program on the TI-59 CROM (Burgan 1979a). In order to use the NFDRS fuel models in the fire behavior calculations, the TSTMDL program of the FUEL subsystem was used to enter NFDRS fuel model parameters, with the specification that the custom fuel models are dynamic. The FIRE1 program of BEHAVE was used to do the calculations for both the "custom" NFDRS fuel models and the NFFL fuel models.

Table 4.—Calculated rate of spread, heat per unit area, and flame length for three NFDRS fuel models and their "similar" (see fig. 21) NFFL fuel models

Fuel model	Calculations by	Rate of spread	Heat per unit area	Flame length
		Ch/h	*Btu/ft²*	*Ft*
B	NFDRS	90	2,875	22
B	BEHAVE	92	6,385	32
4	BEHAVE	193	3,202	33
G	NFDRS	19	2,250	9.6
G	BEHAVE	19	994	6.6
10	BEHAVE	19	1,488	8.1
A	NFDRS	81	50	3.5
A	BEHAVE	82	69	3.8
1	BEHAVE	119	92	5.2

Rate of spread is essentially the same whether NFDRS or BEHAVE is used to do the calculations. The spread equations in the two systems are nearly the same. But, unless there are only fine fuels as in the case with fuel model A, the calculated heat per unit area (H/A) and flame length (FL) will be different. Notice that H/A and FL are higher when fuel model B is used in BEHAVE than they are with the NFDRS calculations. The opposite is true for fuel model G; the BEHAVE predictions are lower.

Now note the relationship between the NFDRS fuel model calculations using the NFDRS equations and the similar NFFL fuel model calculations using BEHAVE. There is a similarity between fuel models A and 1, B and 4, and G and 10. But the actual calculated values can be very different. Specifically, fuel model 1 has significantly higher rates of spread than fuel model A. When the windspeed is increased to 10 mi/h, the difference is even more pronounced. The rate of spread for fuel model 1 is 345 ch/h as compared to 129 ch/h for fuel model A.

Generalizations should not be made based on these examples. Under other environmental conditions, relationships could reverse. Conclusion: A custom fuel model should not be used in BEHAVE unless it is thoroughly tested using the program TSTMDL.

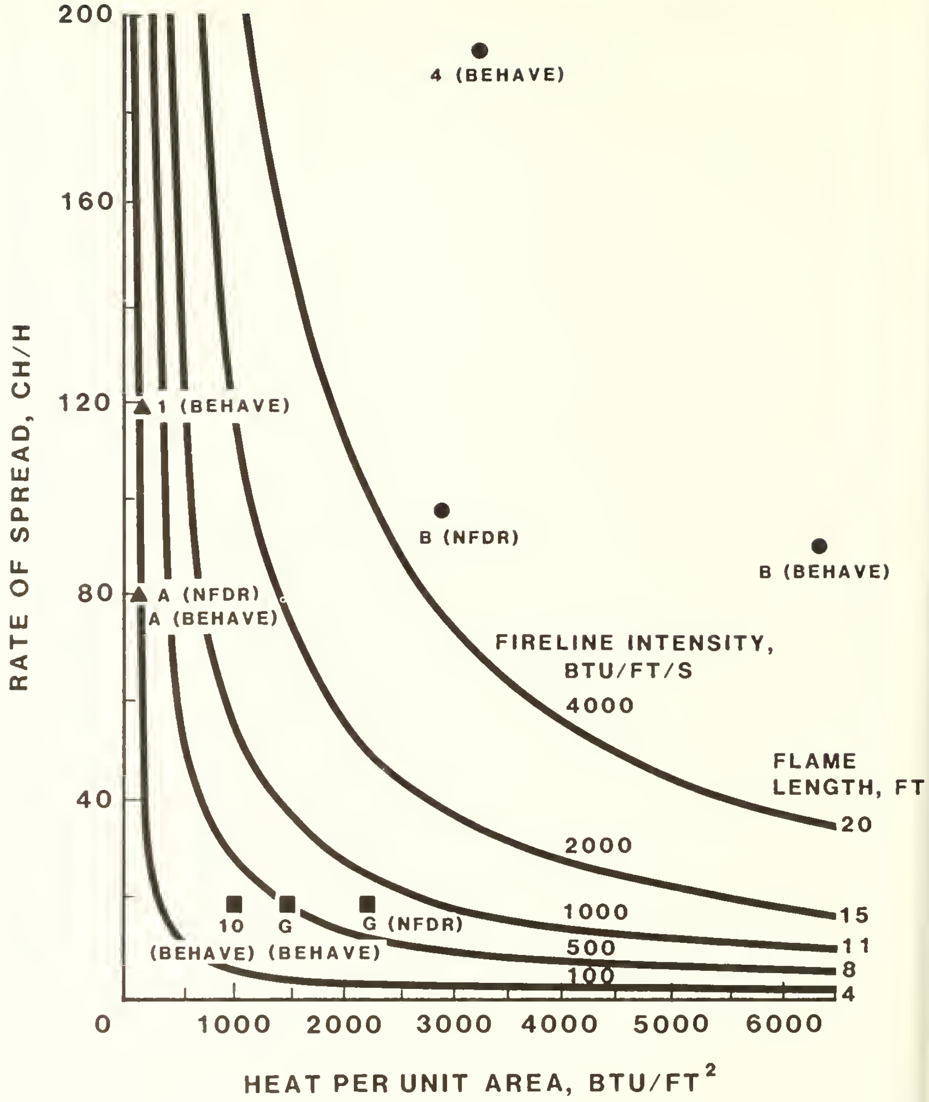

Figure 22.—The values shown in table 4 plotted on a fire characteristics chart.

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Andrews, Patricia L. BEHAVE: fire behavior prediction and fuel modeling system—BURN Subsystem, part 1. General Technical Report INT-194. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1986. 130 p.

Describes BURN Subsystem, Part 1, the operational fire behavior prediction subsystem of the BEHAVE fire behavior prediction and fuel modeling system. The manual covers operation of the computer program, assumptions of the mathematical models used in the calculations, and application of the predictions.

KEYWORDS: fire, fire behavior prediction, fire spread, fire intensity

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The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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Herbicides for Forest Weed Control in the Inland Northwest:

A Summary of Effects on Weeds and Conifers

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PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

RESEARCH SUMMARY

The damaging effects of herbicide treatments on a wide variety of competing species and crop conifers are cataloged for easy reference by silviculturists seeking the best herbicide prescription for plant communities common to the Inland Northwest. For each species the results of herbicide application are given, along with the source of information. Each item includes species, herbicide, application rate, carrier, adjuvants, total mix application rate, application season, plant injury (for up to 4 years), and a reference to the source of the information. Special notes on the use of selected herbicides are also provided.

Available data include the effects of 16 basic herbicides on 34 species, genera, or plant forms, and on 10 conifer species.

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Herbicides for Forest Weed Control in the Inland Northwest: A Summary of Effects on Weeds and Conifers

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INTRODUCTION

Successful silvicultural weed control (the suppression of vegetation that competes with or otherwise interferes with the survival and growth of "crop" trees) with herbicides depends on applying an appropriate chemical to susceptible vegetation in a formulation that maximizes the ratio of plant kill to economics of spray application. Planning of effective herbicide spray programs in the Inland Northwest is hindered by the complexity of a large variety of "weed" species, variable efficacy of numerous herbicides, and highly variable environmental conditions. This report is an up-to-date compilation of results from previous herbicide applications in this region. Included are chemical formulations, rate of active ingredient, carrier, adjuvants, total mix rate, timing of application, weed control, and conifer injury resulting from sprays. All reports of treatments are included regardless of effectiveness in weed control. This data base was designed to assist in spray project planning. Data are stratified by weed and conifer species, chemical, season of application, and active ingredient rate.

This publication is the third in a series first published by Potlatch Corporation as "Shrub Control in the Inland Northwest - A Summary of Herbicide Test Results," RN-83-4, in February of 1983 and revised in December 1983. In this version, information from the Intermountain Research Station has been merged with data summarized in the original Potlatch reports. Results include data from the Research Station's own research as well as information obtained from Inland Northwest land managers with experience in the use of herbicides. The title of the publication has been modified to reflect the large amount of additional information on herbicide control of herbaceous forest weeds. In addition, some salient features of the most useful herbicides are emphasized. A general reference figure (fig. 1) has been added to facilitate a preliminary search for herbicides and their relative effects on important forest weed species and conifers in the Inland Northwest. We have added a table (table 1) of herbicides registered for forest weed control in the Inland Northwest (Washington, Oregon, Idaho, and Montana), including chemical, product, formulation, active ingredient per unit of product, manufacturer, cost, and labeled use.

Writing efficient weed control prescriptions requires that information be compiled in a form where various treatments can be easily compared. Miller and Kidd (21) have described one process for screening treatments to select the optimum chemical brush control prescription. This report should aid silviculturists in preparing prescriptions for chemical site preparation and conifer release treatments.

DESCRIPTION OF DATA FORMAT

Vegetation control summaries for Inland Northwest situations have been written by numerous authors, have appeared in scattered publications, and have used a variety of formats to describe treatment effectiveness. This report is a compilation of data from these publications and from unpublished sources. The majority of the data come from the Northern Rocky Mountains, but several reports are from west of the Cascade Mountains. The herbicides listed generally are registered for forestry use in Idaho, Oregon, Washington, and Montana. However, because many of the results reported are from experimental applications, they may or may not be in accordance with label information or State restrictions. Before using any herbicide, check for label compliance and current State Department of Agriculture registration.

To overcome the fragmented nature of existing herbicide information, we have indexed data in this report by variables crucial to the success of a spray operation. Each item in the data format will be discussed.

Test Results by Species and Herbicide

Herbicide information is arranged alphabetically by shrub species, followed by herbaceous species or species groups, and finally by conifer species. Within species, data are grouped by herbicide treatment. Tank mixes (combinations of herbicides) are indicated by including the respective herbicides within parentheses (), and results must be considered in response to the combination of chemicals, not to any one alone. Herbicide trade names are listed as reported in supporting references. A check with the cited publication or with the office supplying the unpublished data should provide information not included in the tables. While some inferences can be drawn for weed control of similar species in other areas, we do not advocate these data for control recommendations outside the Inland Northwest.

There are no data in this report on the response of crop conifers other than injury by herbicide treatment.

Information on posttreatment tree survival and growth is not as readily available as the data presented on plant injury. The user is cautioned that weed control may not always equate with better crop performance in a complex forest ecosystem. Various side effects of an herbicide treatment can result in counterproductive changes in plant and animal communities. Treatment-induced changes in animal, insect, and disease populations should also be considered. Changes in the availability of the basic growth factors—water, nutrients, light, and heat—may be both beneficial and detrimental.

Application Rate and Mix

Most treatment rates are described in pounds active ingredient per acre. Some ground sprays are listed as LBHG for pounds active ingredient per hundred gallons of spray mix per acre. These are usually applied as high-volume ground sprays. Several herbicides and mixtures are listed by volume. For instance, Tordon 101 is a mixture of picloram and 2,4-D, and the rate is listed as gallons of product per acre.

The total spray volume per acre is listed for aerial applications. Some data are from ground (backpack) applications. Ground sprays are coded differently in the "Gal/Acre" column. The codes are as follows:

G—Ground broadcast spray. Total gallons per acre may also be specified (such as G20 for 20 gallons per acre).

GDP—Hand-sprayed to the drip point. The drip point occurs when spray is applied to individual plants until it first begins to run off foliage surfaces.

S—Spot treatment where spray application is restricted to a localized area (such as a 4- by 4-ft square). Total gallons per acre may also be specified.

D—Shrub and soil drench around individual plants as was often done in ground-applied *Ribes* control sprays.

Ground application generally produces better control than aerial spraying because of more complete coverage. Therefore, if ground results are used per-acre rates should be increased for aerial application.

Treatment Season

Timing of herbicide application is dependent upon several interrelated factors such as brush phenology, localized environmental conditions, and mode of action of specific herbicides. While the tables include a spray season related to dates, these are only approximately related to the phenology of treated plants. For example, most forbs and grasses will cure earlier on dry sites than on more mesic sites. A useful discussion of these considerations was provided by Gratkowski (9). His terminology of seasons of application is used:

Dormant or budbreak—Late winter or early spring at beginning of spring flush of growth. Buds on conifers swelling or bursting; buds on shrubs bursting or new leaves unfolding.

Early foliar—Period of active growth; approximately three-fourths of new leaves on shrubs full size. Period of maximum susceptibility to herbicides.

Late foliar—During midsummer, usually mid-July to early August, after cessation of growth on conifers and shrubs. All leaves full size and hardened. New terminal buds well developed on conifers.

Late summer—Usually late August to early September, long after cessation of spring flush of growth.

Fall—Late September to November, after leaf fall; conifers usually dormant.

Weed Control Data

Weed control is reported as percentage top kill and percentage plant kill in the first, second, or third year. First-year control data were collected during the same growing season as herbicide application. Second-year data were collected during the growing season following spraying, and so forth. Percentage top kill refers to percentage crown volume reduction or percentage crown cover reduction. In either case, the top-kill data are a reasonable estimate of competition reduction. Where references reported control data on other than a percentage basis, percentage control estimates were calculated from original data to present a uniform control scale. Some references reported top-kill data for more than 1 year. Comparing these figures gives an estimate of rapidity of shrub recovery. Percentage plant kill (percentage of examined shrubs that were completely killed) is reported where available.

Careful comparison of study results will reveal many inconsistencies and even contradictions in the results. Tests were installed in different years, at different phenological stages, on different sites, and under different weather conditions. These and other factors produced variation in results. More research and greater experience with the materials should reduce this variation and produce more predictable results. A complete reading of the original reference or contact with the reporter may explain the variation.

Tree Injury

Conifer injury caused by spraying is reported where available. The following codes describe injury:

0 - No effect.

1 - 0 to 10 percent defoliation, no bud injury.

2 - 0 to 10 percent defoliation, slight tip curl, no bud injury.

3 - 11 to 40 percent defoliation, slight bud kill.

4 - 40+ percent defoliation, moderate bud kill.

5 - Slight to moderate top kill, 50+ percent defoliation.

6 - Trees killed.

P - Follows numerical injury code when trees were protected from chemical spray.

Defoliation refers to foliage present when sprayed. Bud injury includes both laterals and terminals produced during the spray season.

A note of caution is appropriate concerning tree damage ratings. Conifers suppressed by an overtopping canopy of competing vegetation are screened from a full herbicide application. Many of the reported damage ratings to conifers may be confounded by this complication.

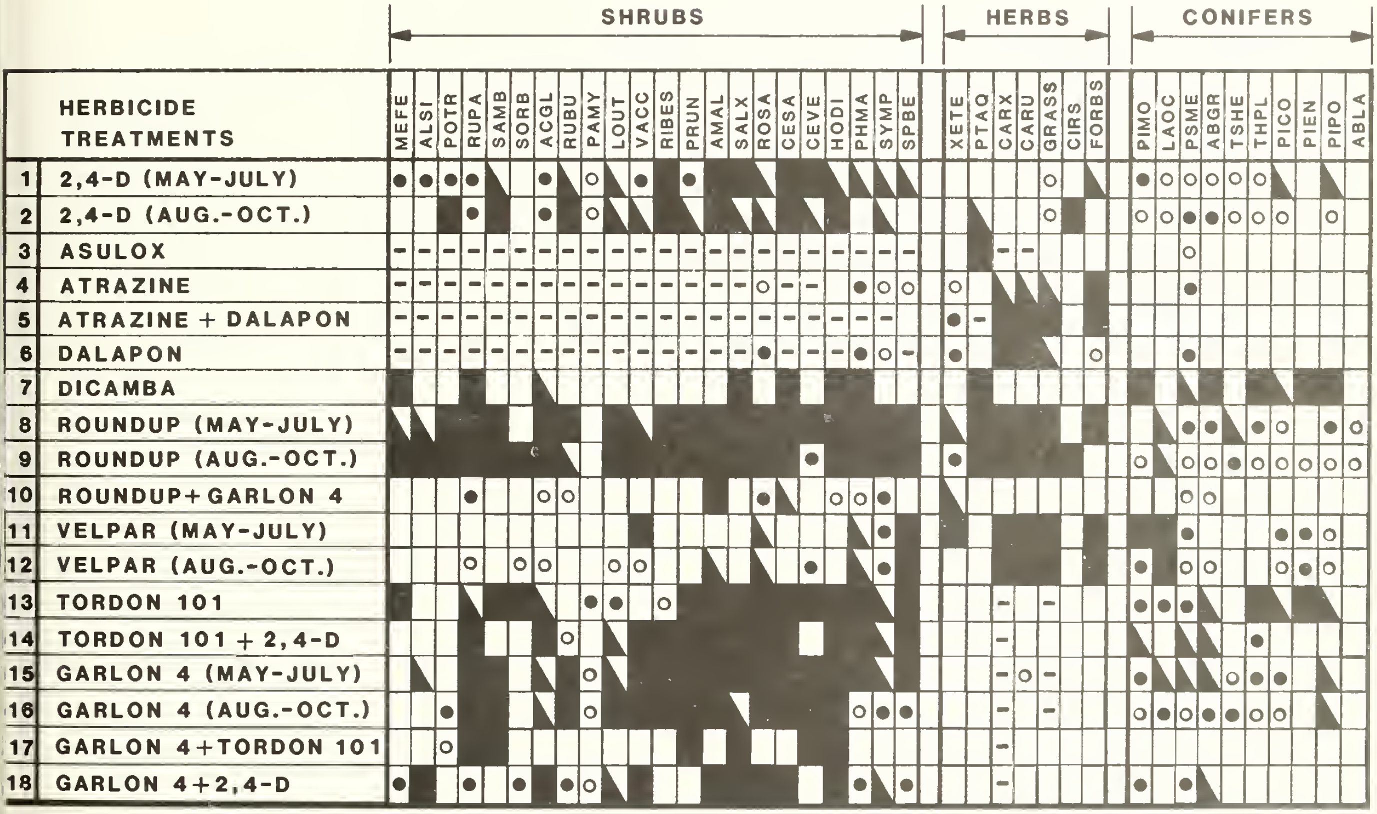
TREATMENT SELECTION

All treatment recommendations must be based on some form of site-specific data on the weed species present, their competitive ranking, and the crop to be benefited. The data presented here permit selection of the most effective **candidate** treatments by weed and crop species. Figure 1 provides the first "rough cut" on candidate treatments for a given competitor or group of competitors and an estimate of crop tree injury that might be expected. It is presented as a quick preliminary survey, but **no prescriptions should be made solely on the basis of this table.**

The species-by-species summary tables of herbicide treatment effects, beginning on page 7, will provide important specifics on rates of application, carriers, adjuvants, timing, tree injury, and the source of data.

While costs of treatments are extremely variable, some comparative herbicide cost data are presented in table 1. Other than this, it is beyond the scope of this paper to estimate total treatment expenses. Users are encouraged to consult the chemical distributors, technical representatives, or the original data source for details.

Finally, prior to deciding on the treatment, the label should be thoroughly scrutinized for compliance with legal restrictions and State registration verified with State agricultural authorities.



KEY :

- VERY SEVERE INJURY OR KILL
- SERIOUS INJURY
- MODERATE INJURY
- LITTLE OR NO INJURY
- NO LOCAL DATA- BUT NOT KNOWN TO INJURE
- INADEQUATE INFORMATION

- The ratings for weeds represent the most severe effects derived from trial compilations.

- Conifer ratings represent the average damage ratings derived from test compilations (see text page 14 concerning conifer ratings).

- All plants rated without reference to rate, adjuvants, or application method.

- Since the effectiveness of many herbicides depend upon the stage of plant development (phenology), calendar dates in this table are only approximate.

- Species & genera codes identified in appendix species list.

Figure 1.—Susceptibility of inland Northwest forest species to herbicides—1984.

Table 1.—Herbicides registered for forestry use in Idaho

Herbicide	Product	Formulation	Active ingredient (lb/gal or %)	Manufacturer	Cost[1]	Labeled for: Site prep	Conifer release	Stem injection
2,4-D	Esteron 99 Concentrate	Ester*	3.8	Dow	$10.50/gal	X	X	
2,4-D	Esteron 6E	Ester*	5.6	Dow	10.50/gal	X	X	
2,4-D	Weedone LV4	Ester*	3.8	Union Carbide	10.50/gal	X	X	
2,4-D	2,4-D LV Ester 4L	Ester*	3.9	Rhone-Poulenc	10.50/gal	X	X	
2,4-D	2,4-D Ester 6L	Ester*	5.7	Rhone-Poulenc	10.50/gal	X	X	
2,4-D	2,4-D LV Ester 4EC	Ester*	4	USS Agri-Chemicals	10.50/gal	X	X	
2,4-D	Brush-Rhap LV 4-D	Ester*	3.8	Vertac	10.50/gal	X	X	
2,4-DP +		Ester*	2					
2,4-D	Weedone 170	Ester*	2	Union Carbide	19.62/gal	X		
2,4-DP +		Ester*	2					
2,4-D +		Ester*	2					
Dicamba	Brush Killer 800		0.5	PBI Gordon		X		
2,4-D	DMA 4	Amine	3.8	Dow	8.00/gal			X[2]
2,4-D	Formula 40	Amine	3.8	Dow	8.00/gal			X[2]
2,4-D	Weedkiller 40A	Amine	3.8	Cenex	8.00/gal			X[2]
2,4-D	Weed-Rhap	Amine	3.8	Vertac	8.00/gal			X[2]
2,4-D	Weedar 64	Amine	3.8	Union Carbide	8.00/gal			X
2,4-D	Amine 4 2,4-D Weed Killer	Amine	3.8	Platte Chemical	8.00/gal			X
Amitrol	Cytrol	Liquid	2	American Cyanamid	18.00/gal		X[3]	
Amitrol	Weed Killer 90	Soluble powder	90%	American Cyanamid	6.13/lb		X[3]	
Amitrol +			15%					
Simazine	Amizine	Wettable powder	45%	Union Carbide	5.10/gal		X[3]	
Asulam	Asulox	Liquid	3.3	Rhone-Poulenc	39.10/gal	X	X	
Atrazine	AAtrex 4L	Liquid	4	Ciba-Geigy	10.10/gal	X	X	
Atrazine	AAtrex Nine 0	Granule	85%	Ciba-Geigy	2.35/lb	X	X	
Atrazine	AAtrex 80W	Wettable powder	76%	Ciba-Geigy	1.85/lb	X	X	
Dalapon	Dowpon Grass Killer	Powder	85%	Dow	1.95/lb	X		
Dalapon	Dowpon M Grass Killer	Powder	72%	Dow	1.75/lb	X	X[4]	
Dicamba	Banvel CST	Amine	1	Velsicol	53.00/gal			X
Dicamba +								
2,4-D	Banvel-520	Ester*	1.9	Velsicol		X		
Dicamba +								
2,4-D	Banvel-720	Amine	1.9	Velsicol		X		
Dichlobenil	Casaron G-4	Granule	4%	Thompson-Hayward	1.10/lb		X	
Dichlobenil	Casaron W-50	Powder	50%	Thompson-Hayward	13.50/lb		X	
Dinitro	Contact Weed Killer	Liquid	30%	Wilbur-Ellis	10.65/gal	X		
Fosamine	Krenite	Liquid	4	DuPont	46.80/gal	X		
Glyphosate	Roundup	Liquid	4	Monsanto	68.00/gal	X	X	
Hexazinone	Velpar L	Liquid	2	DuPont	44.00/gal		X	
Hexazinone	Velpar	Soluble powder	90%	DuPont	20.00/lb		X	
Hexazinone	Pronone 10G	Granule	10%	Proserve	2.45/lb	X	X	
Hexazinone	Pronone 5G	Granule	5%	Proserve	1.60/lb	X	X	
Picloram	Tordon K	Liquid	2	Dow	85.90/gal	X		
Picloram	Tordon 22K	Liquid	2%	Dow	85.90/gal	X		
Picloram	Tordon 10K	Pellets	12%	Dow	3.80/lb	X		
Picloram +			0.5					
2,4-D	Tordon 101	Amine	2	Dow	20.50/gal	X		X
Picloram +			0.3					
2,4-D	Tordon 101R	Amine	1	Dow	16.90/gal			X
Picloram +			0.3					
2,4-D	Tordon RTU	Amine	1	Dow	19.80/gal			X
Triclopyr	Garlon 4	Ester	4	Dow	69.50/gal	X	X	
Triclopyr	Garlon 3A	Amine	3	Dow	52.00/gal	X		

*Requires State waiver for summer application in Latah, Nez Perce, and Clearwater Counties.
[1]Prices courtesy of Wilbur-Ellis Co. May 1984 (quoted for comparison purposes only).
[2]Hardwoods only.
[3]Directed spray.
[4]For conifer release apply only with atrazine.

COMMENTS ON SELECTED HERBICIDES

Some extra information is warranted for selected herbicides in this report. More information on these or the other herbicides can be obtained from the sources cited in the summary tables or from the manufacturer.

Atrazine

While atrazine has not been consistently effective in controlling pinegrass and elk sedge in the Inland Northwest, it has on occasion been effective. On an assortment of other grasses, mostly annual grasses, it has done well. Its cost advantage makes it a prime candidate for more detailed studies to improve its consistency.

Dalapon

Dalapon is generally quite effective on grasses, but results in the Northern Rocky Mountains have been inconsistent. As with atrazine, it is inexpensive and a candidate for study to improve its reliability. Studies in the Northern Rocky Mountains tend to weakly confirm the contention that a mix of dalapon and atrazine offers a broader spectrum of weed control and protection of some conifers from dalapon damage.

Garlon

Of the two Garlon formulations, Garlon 4 is more effective as a foliar spray on shrubs. Applications during the foliar season generally produce good control. Dormant applications in oil have proven effective west of the Cascades. Garlon 4 is labeled for conifer release sprays except over pines. Ponderosa and lodgepole pine are easily injured by foliar sprays. Western white pine appears more tolerant. Directed sprays should be used to prevent overspraying and injuring pines. Garlon 4 is effective on evergreen shrubs, especially if oil is added to the spray mixture. The oil-in-water emulsion readily penetrates the leathery perennial leaves producing good control of such species as *Ceanothus velutinus*. Garlon 4 is also effective as a basal spray on hardwood clumps.

The short residual toxicity provided by Garlon, plus its broad spectrum effectiveness on shrub species, makes Garlon a somewhat superior product for site preparation in some shrub communities.

As with Tordon, 2,4-D, and 2,4-DP, the tolerant grasses and sedges will occupy the holes created by Garlon control of the woody vegetation.

Garlon 3A is effective as a cut-stump treatment on hardwoods and is also effective for stem injection on hardwoods and conifers.

Roundup

Roundup is a broad-spectrum herbicide of considerable utility in both site preparation and conifer release. Evergreen plants, including conifers, are tolerant of Roundup except during the flushes of new growth when foliage is succulent and readily absorbs the chemical. It is strictly a foliage-active herbicide with little if any root absorption. Healthy active foliage is required to absorb enough chemical for translocation to all parts of the plant at toxic levels. Treatment of sprouting-established plants soon after burning or cutting will probably not be effective due to the dilution of a relatively small amount of absorbed chemical in a large root system. Results will also be poor on plants that are stressed or damaged.

Although Roundup is only marginally effective on evergreen plants, it may prove effective when applied during the spring growth flush if the proportion of new succulent to old, hardened foliage is relatively high, as with 1- to 3-year-old plants. When new, unhardened foliage is a small percentage of the total, damage will be restricted to the new growth. The addition of extra surfactant will often improve treatment effectiveness, especially on evergreen plants.

Although Roundup is a relatively broad-spectrum herbicide, in competitive communities with species in different phenological stages of development it may be difficult to treat at a time when all species are vulnerable or at a time when the competition is vulnerable and the crop is not. Late-season flushes of conifer growth may be damaged by Roundup application. Treating over crop trees during active growth requires shielding the trees from direct herbicide contact.

When used as a conifer release treatment with the chemical applied over unshielded trees, make sure that the new foliage has hardened (that is, has taken on the same color as older foliage) and that late-season growth flushes are not occurring. (These recommendations do not apply to western larch and may also be risky on western redcedar.) Foliage condition is a better indicator of the safe phenological stage than is bud set.

Because the effectiveness of Roundup varies inversely with the amount of water with which it is mixed, it should be applied with as little water as possible consistent with equipment capabilities and label restrictions. The standard for aerial spraying of shrub communities is 7.5 to 10 gal/acre total mix. Scattered low shrubs and grass and forb communities may be treated at lower total mix rates. Ultralow volume applications with spinning disk or wiper-type applicators are effective in many situations.

The high probability of rain during late May, June, and early July in the Inland Northwest makes treatments risky and difficult to schedule when herbaceous vegetation is most vulnerable.

While Roundup seems to have performed well for most users, for some it has been inconsistent under essentially identical conditions of application, vegetation, and weather.

Tordon Products

Tordon 101 and other Tordon products (products containing picloram) are effective in controlling a wide assortment of woody vegetation in site preparation treatments. Tordon's long soil residual toxicity requires that reforestation efforts not be undertaken within 7 to 8 months of application. Label-recommended waiting periods should be strictly adhered to. Grasses and sedges, if present on the treated site, will quickly fill the

gaps in the ecosystem created by the demise of the shrubs. Tordon cannot be used for conifer release.

Velpar and Pronone

Pronone, while not featured in any of the studies reported here, is similar to DuPont's gridballs and their DPX 3674—2-G, which have been used in several of the reported results.

Hexazinone, the active ingredient in both Velpar and Pronone (granular 5 or 10 percent) has proven particularly effective on Inland Northwest herbaceous vegetation. It acts both as a foliage and soil-active herbicide in the liquid formulation (Velpar L) and strictly as a soil-active chemical in the granular formulation. It has a moderately long soil residual. Both formulations have been applied to ponderosa pine throughout the growing season with little damage. Other species are less tolerant, especially to application during the spring growth flush. Western white pine and western larch are susceptible at any time of year.

These products have an advantage over chemicals that depend upon foliar absorption in that they can be applied at any time of the year (except on frozen ground or snow) or in any weather. Posttreatment precipitation is necessary to "activate" the soil-active action. Photo decomposition will tend to deactivate material that remains on the surface of soil or foliage for an extended period. This is probably more of a problem with the liquid formulation than with the granular one. Vegetation treated in late summer or fall will "green up" normally in the spring, then will die as the chemical is absorbed by the root system and translocated to the site of action in the foliage. Like its triazine relative atrazine, hexazinone appears to have a growth-stimulating effect beyond that provided by strict weed control.

On moderate to steeply sloping ground, the chemical has a pronounced tendency to move by gravity in the soil, thus displacing the treatment effect downslope when applied as spots or bands.

Hexazinone products have not controlled hardwood competition as well in the Inland Northwest as they have apparently done in the Southern States. However, due to their mode of action (root absorption and translocation to their site of activity in the photosynthetic system), they may be effective on sprouting plants.

2,4-D

The oldest and one of the most used of the modern synthetic herbicides, 2,4-D is available as either the ester or amine formulation. The ester formulation generally produces better shrub control. For best results, it is most often used in combination with Garlon 4, picloram (as Tordon 101), dicamba, or other herbicides. 2,4-D now seems best suited for situations where, following harvest and site preparation, there is a rapid invasion of forbs such as fireweed (*Epilobium* spp.), astragulus, antennaria, and so forth. Its cost, in comparison to newer herbicides, makes it an attractive alternative where conditions warrant its use.

The low volatile ester formulation will volatilize and move off site if subjected to high temperatures (>90 °F, 32 °C). This can occur during midsummer applications. 2,4-D can volatilize from leaf surfaces and move off site on air currents even when ambient air temperatures are <90 °F due to the thermal characteristics of target surfaces. Injury to adjacent conifers may be insignificant, but agricultural and garden crops may be severely damaged. Grapes and tomatoes are sensitive to 2,4-D and are easily damaged by drift and vapors from nearby spraying. Extreme caution must be used when spraying 2,4-D ester near agricultural lands and homesites.

HOW TO HELP IN UPDATING INFORMATION

Recipients of this report who have additional information concerning the subject that they feel should be included are encouraged to make copies of, and fill out, the enclosed form on pages 64–66. Please return the form to the authors for incorporation into a future, updated report.

We are also investigating the feasibility of establishing accessible computer data sets at USDA Forest Service Fort Collins Computer Center and on AgNet for those having access to these systems.

SUMMARY TABLES OF HERBICIDE EFFECTS

Key to abbreviations:

"NT" under ADJUVANTS = Nalco-trol

"TV" under ADJUVANTS = Transvert

"SURFACT" under ADJUVANTS = Surfactant

"*" under % TOP-KILL YR 3 = TOP-KILL YEAR 4

In the following tables, the letters A through Z following reference numbers indicate separate study sites within the scope of the reference.

For a more detailed explanation of information in the tables, refer to the previous sections in this publication.

MOUNTAIN MAPLE (ACER GLABRUM)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	0.75 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	4	.	.	.	27
2,4-D ESTER	1.5 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	3	.	.	.	27
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	0	0	0	2	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	2	.	.	.	27
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	13	0	0	2	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	13	0	0	3	13
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	20	.	.	.	2	51
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	9	0	8	1	22
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	9	0	8	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	.	35	0	0	3	13
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	.	3	.	0	.	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	.	54	.	0	.	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	.	16	.	0	.	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	.	63	.	.	.	32
GARLON 3A	3 LB	WATER		10	L SUMMER	.	0	.	0	0	20
(GARLON 3A +	3 LB					.	.	.	.	.	
ROUNDUP)	0.5 LB	WATER		10	L SUMMER	.	22	.	0	0	57A
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	18	0	0	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	69	37	38	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	71	35	27	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L FOLIAR	.	3	0	0	2	17
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	71	.	.	1	19
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	41	17	6	1	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	56	6	18	3	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	73	.	.	1	19
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	41	25	0	2	20
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	66	48	0	2	20
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	59	27	33	2	22
GARLON 4	5 LB	WATER	3 QT DIESEL	10	L SUMMER	.	73	39	0	3	20
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	16	0	7	2	13
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	18	0	30	3	13
(GARLON 4 +	3 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT MORACT	15	L FOLIAR	.	67	.	.	5	57B
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	85	55	14	2	22
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	59	4	7	2	22
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	73	70	40	5	13
ROUNDUP	0.75 LB	WATER		7.5	L FOLIAR	.	0	1	0	1	16
ROUNDUP	1 LB	WATER		10	L FOLIAR	.	10	23	4	1	16
ROUNDUP	1.5 LB	WATER	1% R-11	5	L FOLIAR	.	0	0	0	0	17
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	59	59	14	0	17
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	76	75	50	0	17
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	43	40	10	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	31	48	14	3	16
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	92	86	60	0	17
ROUNDUP	2 LB	WATER	1% R-11,NT	10.7	L FOLIAR	60	.	.	.	2	44F
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	90	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	8	46	5	3	16
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	48	56	40	3	16
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	40	.	.	.	4	44C
ROUNDUP	1 LB	WATER		10	L SUMMER	.	0	0	0	0	16

MOUNTAIN MAPLE (ACER GLABRUM)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	2 LB	WATER		10	L SUMMER	.	0	0	0	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	61	63	10	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	49	18	0	0	13
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	.	40	.	.	0	50A
ROUNDUP	2 LB	WATER	.6% R-11	G20	L SUMMER	.	40	.	.	2	43B
ROUNDUP	2 LB	WATER		10	L SUMMER	20	50	.	.	0	50C
ROUNDUP	3 LB	WATER		10	L SUMMER	25	75	.	.	0	50D
ROUNDUP	3 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43J
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	.	100	.	.	0	42
ROUNDUP	3 LB	WATER		10	L SUMMER	.	80	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	80	.	.	.	52G
ROUNDUP	3 LB	WATER		10	L SUMMER	.	60	.	.	.	52T
ROUNDUP	3 LB	WATER		10	L SUMMER	.	40	.	.	.	52V
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER	1% SURFACT	10	L SUMMER	.	60	.	.	.	52X
(ROUNDUP +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	5% R-11,TV	10	L SUMMER	.	20	.	.	6	43A
(ROUNDUP +	2 LB					.	.	.	.	.	
GARLON 4)	1 LB	WATER		10	L SUMMER	.	14	0	0	0	13
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	.	.	80	.	31
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	50	0	0	.	13
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	.	19	.	0	.	32
TORDON 101	1 GAL	WATER		10	L SUMMER	.	35	8	0	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	97	92	83	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	.	35	23	20	.	13
(TORDON 101 +	1 GAL	WATER				.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	.	14	0	0	.	13
(TORDON 101 +	1.5 GAL	WATER				.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	10	0	0	.	13
VELPAR GB	10-20#	GRIDBAL			DORMANT	.	0	.	.	.	56
VELPAR L	2 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
(VELPAR +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	0	.	4	43E
(VELPAR +	1 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	0	.	4	43G

SITKA ALDER (ALNUS SINUATA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	40	.	.	52R
(2,4-D +	2 LB					.	.	.	.	.	
2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	20*	.	4	43F
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	0	.	.	52R
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	60	.	.	.	4	44B
(GARLON 4 +	3 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT MORACT	15	L FOLIAR	.	100	.	.	5	57A
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	30	.	.	52R
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	60	.	.	.	2	58B
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	40	.	.	.	2	44D
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	80	.	.	52R

SITKA ALDER (ALNUS SINUATA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	60	.	.	.	4	44A
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	40	.	.	.	4	44C
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43C
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43D
ROUNDUP	2 LB	WATER		10	L SUMMER	25	100	.	.	0	50B
ROUNDUP	2 LB	WATER		10	L SUMMER	0	75	.	.	0	50C
ROUNDUP	3 LB	WATER		10	L SUMMER	50	100	.	.	0	50D
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	.	80	.	.	0	42
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52G
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52V

SERVICEBERRY (AMELANCHIER ALNIFOLIA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	0.5 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	3	.	.	.	27
2,4-D ESTER	1.5 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	12	.	.	.	27
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	75	75	75	2	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	43	.	.	.	27
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	91	75	63	2	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	93	77	69	3	13
2,4-D ESTER	0.5 LBHG	WATER		GDP	L FOLIAR	.	33	.	0	.	7
2,4-D ESTER	2 LBHG	WATER		GDP	L FOLIAR	.	50	.	0	.	7
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	40	.	.	52R
2,4-D ESTER	4 LBHG	WATER		GDP	L FOLIAR	.	44	.	0	.	7
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	60	.	.	.	2	51
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	91	83	1	22
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	63	38	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	.	98	73	50	3	13
(2,4-D +	0.5 LBHG					.	.	.	.	.	
AMITROL)	1 LBHG	WATER		GDP	L FOLIAR	.	43	.	0	.	7
AMITROL	4 LBHG	WATER		GDP	L FOLIAR	.	0	.	0	.	7
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	50	.	.	52R
GARLON 3A	3 LB	WATER		10	L SUMMER	.	14	.	0	0	20
(GARLON 3A +	3 LB					.	.	.	.	.	
ROUNDUP)	0.5 LB	WATER		10	L SUMMER	.	23	.	6	0	57A
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	94	46	29	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	99	92	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	100	100	5	13
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	51	.	.	1	19
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	98	77	40	1	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	52	43	3	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	89	.	.	1	19
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	86	73	2	22
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	78	53	2	13
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	99	72	55	3	13
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	100	100	2	22
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	100	100	2	22
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	20	.	.	52R
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	100	93	86	5	13

SERVICEBERRY (AMELANCHIER ALNIFOLIA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	0.75 LB	WATER		7.5	L FOLIAR	.	28	26	0	1	16
ROUNDUP	1 LB	WATER		10	L FOLIAR	.	99	99	92	1	16
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	100	100	100	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	99	99	90	3	16
ROUNDUP	2 LB	WATER	3%	S	L FOLIAR	100	.	.	.	.	48
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	60	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	100	100	100	3	16
ROUNDUP	1 LB	WATER		10	L SUMMER	.	90	69	69	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	87	74	57	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	100	98	88	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	100	96	88	0	13
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52H
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	.	100	.	.	0	42
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	90	.	.	.	52S
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	100	.	.	.	52S
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	100	.	.	.	52G
(ROUNDUP +	2 LB					.	.	.	.	.	
GARLON 4)	1 LB	WATER		10	L SUMMER	.	82	78	57	0	13
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	.	.	97	.	31
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	86	82	71	.	13
TORDON 101	1 GAL	WATER		10	L SUMMER	.	83	54	0	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	100	100	100	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	.	98	95	88	.	13
(TORDON 101 +	1 GAL	WATER				.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	.	100	86	60	.	13
(TORDON 101 +	1.5 GAL	WATER				.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	92	55	33	.	13
VELPAR G	1.4 LB	GRANULE		G	L SUMMER	.	60	.	.	.	52S
VELPAR L	2 LB	WATER	DEFOAMER	10	L SUMMER	.	11	.	.	1	19
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19

BEARBERRY (ARCTOSTAPHYLOS UVA-URSI)

2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	60	.	.	52R
ROUNDUP	2 LB	WATER	.5%FIRECHEM	G10	E FOLIAR	20	.	.	.	.	47
ROUNDUP	4 LB	WATER		S	E FOLIAR	80	.	.	.	0P	59C
ROUNDUP	0.3 LB	WATER		S1.5	L FOLIAR	0	.	.	.	0P	45

OREGON GRAPE (BERBERIS SPP.)

2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	0	.	.	52R
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	20	.	.	.	2	51
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	60	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	0	.	.	.	52F
ATRAZINE	10 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52L
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52L
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	40	.	.	52R

OREGON GRAPE (BERBERIS SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	0	.	.	52R
ROUNDUP	1 LB	WATER		S7	E FOLIAR	0	.	.	.	0P	53B
ROUNDUP	1 LB	WATER		S10	E FOLIAR	60	.	.	.	0P	53C
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52L
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	40	.	.	.	2	58B
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	0	.	.	52R
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	0	.	.	.	52H
ROUNDUP	3 LB	WATER		10	L SUMMER	.	0	.	.	.	52H
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52L

REDSTEM CEANOTHUS (CEANOTHUS SANGUINEUS)

2,4-D ESTER	0.75 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	45	.	.	.	27
2,4-D ESTER	1.5 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	60	.	.	.	27
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	87	83	67	2	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	98	93	90	2	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	75	.	.	.	27
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	90	100	100	3	13
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	80	.	.	52R
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	79	0	33	1	22
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	40	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	40	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	50	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	50	.	.	.	52F
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	92	88	78	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	.	99	98	93	3	13
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	.	82	.	.	.	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	.	100	.	100	.	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	.	80	.	.	.	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	.	75	.	.	.	32
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	60	.	.	52R
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	100	100	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	100	100	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	100	100	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L FOLIAR	.	85	86	73	2	17
GARLON 4	2 LB	WATER	1%NT,MORACT	10.6	L FOLIAR	80	.	.	.	2	44K
GARLON 4	2 LB	WATER	3%NT,MORACT	10	L FOLIAR	80	.	.	.	2	44L
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	100	.	.	.	5	44B
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	89	.	.	1	19
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	94	95	88	1	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	100	100	3	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	.	.	1	19
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	98	38	85	2	22
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	96	92	2	13
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	100	100	3	13
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	98	87	64	2	22
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	20	.	.	52R
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	100	100	100	5	13
ROUNDUP	1 LB	WATER		10	L FOLIAR	.	82	82	67	1	16

REDSTEM CEANOTHUS (CEANOTHUS SANGUINEUS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	1.5 LB	WATER	1% R-11	5	L FOLIAR	.	74	54	25	0	17
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	85	56	22	0	17
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	100	96	80	0	17
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	90	64	41	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	100	100	95	0	17
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	80	.	.	.	2	44D
ROUNDUP	2 LB	WATER	3% NT,DYE	10.6	L FOLIAR	80	.	.	.	2	44E
ROUNDUP	2 LB	WATER	1% R-11,NT	10.7	L FOLIAR	80	.	.	.	2	44F
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	90	.	.	52R
ROUNDUP	2 LB	WATER		10	L SUMMER	.	88	87	69	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	95	88	86	0	13
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	.	100	.	.	0	50A
ROUNDUP	2 LB	WATER		10	L SUMMER	25	100	.	.	0	50C
ROUNDUP	3 LB	WATER		10	L SUMMER	25	100	.	.	0	50D
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	.	80	.	.	0	42
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	90	.	.	.	52H
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	90	.	.	.	52H
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52T
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52V
ROUNDUP	3 LB	WATER		10	L SUMMER	.	40	.	.	.	52W
(ROUNDUP +	2 LB					.	.	.	.	.	
GARLON 4)	1 LB	WATER		10	L SUMMER	.	64	30	20	0	13
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	81	59	62	.	13
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	.	84	.	80	.	32
TORDON 101	1 GAL	WATER		10	L FOLIAR	.	1	0	0	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	100	100	100	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	.	91	100	100	.	13
(TORDON 101 +	1 GAL	WATER				.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	.	94	95	71	.	13
(TORDON 101 +	1.5 GAL	WATER				.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	65	21	0	.	13
WEEDONE 170	3 QT	WATER	3 QT DIESEL	G15	L SUMMER	.	73	.	.	.	23
WEEDONE 170	6 QT	WATER	3 QT DIESEL	G15	L SUMMER	.	100	.	.	.	23

SNOWBRUSH (SLICK LEAF) CEANOTHUS (CEANOTHUS VELUTINUS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	.	.	50	.	3	39
2,4-D ESTER	2 LB	WATER		10	E FOLIAR	.	.	40	.	3	39
2,4-D ESTER	4 LB	WATER		G25	E FOLIAR	.	71	70	25	.	14
2,4-D ESTER	2 LBHG	WATER	5% DIESEL	GDP	L FOLIAR	.	96	.	20	.	7
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	50	.	.	52R
2,4-D ESTER	4 LBHG	WATER	5% DIESEL	GDP	L FOLIAR	.	100	.	20	.	7
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	40	.	.	.	2	51
2,4-D ESTER	4 LB	WATER		G25	L FOLIAR	.	45	28	21	.	14
2,4-D ESTER	2 LB	WATER		10	L SUMMER	.	.	60	.	2	39
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	30	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	20	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	30	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	30	.	.	.	52F
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	35	.	.	1	57E

SNOWBRUSH (SLICK LEAF) CEANOTHUS (CEANOTHUS VELUTINUS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	4 LB	WATER		G25	FALL	.	2	13	7	.	14
(2,4-DP +	2 LBHG					.	.	.	.	.	
AMITROL)	4 LBHG	WATER		GDP	L FOLIAR	.	97	.	70	.	7
AMITROL	8 LBHG	WATER		GDP	L FOLIAR	.	32	.	0	.	7
GARLON 3A	4 LB	WATER		G25	E FOLIAR	.	93	94	57	.	14
GARLON 3A	4 LB	WATER		G25	L FOLIAR	.	65	60	43	.	14
GARLON 3A	4 LB	WATER		G25	FALL	.	0	3	0	.	14
GARLON 4	1 LB	OIL		10	DORMANT	.	90	.	.	1	39
GARLON 4	2 LB	OIL		10	DORMANT	.	.	95	.	.	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	.	.	95	.	3	39
GARLON 4	1.5LB	WATER		10	E FOLIAR	.	95	.	.	3	39
GARLON 4	2 LB	WATER	2 QT DIESEL	10	E FOLIAR	.	.	95	.	.	39
GARLON 4	4 LB	WATER		G25	E FOLIAR	.	87	91	75	.	14
GARLON 4	2 LB	WATER	1%NT,MORACT	10.6	L FOLIAR	60	.	.	.	2	44K
GARLON 4	2 LB	WATER	3%NT,MORACT	10	L FOLIAR	60	.	.	.	2	44L
GARLON 4	4 LB	WATER		G25	L FOLIAR	.	97	99	75	.	14
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	100	.	.	.	5	44B
GARLON 4	1.5 LB	WATER		10	L SUMMER	.	.	75	.	3	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	76	70	52	2	20
GARLON 4	2 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	43	.	.	4	57E
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	99	96	90	2	20
GARLON 4	5 LB	WATER	3 QT DIESEL	10	L SUMMER	.	97	97	90	3	20
GARLON 4	4 LB	WATER		G25	FALL	.	7	61	0	.	14
(GARLON 4 +	1 LB										
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	67	.	.	3	57E
(GARLON 4 +	1 LB										
2,4-D ESTER)	1 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	30	.	.	2	57E
(GARLON 4 +	1.5 LB										
2,4-D ESTER)	1.5 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	76	.	.	3	57E
(GARLON 4 +	2 LB										
2,4-D ESTER)	1 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	90	.	.	3	57E
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON K)	0.5 LB	WATER		10	E FOLIAR	.	.	95	.	.	39
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON 101)	1 GAL	WATER		10	E FOLIAR	.	.	95	.	.	39
KRENITE	8 LB	WATER		G25	E FOLIAR	.	92	94	77	.	14
KRENITE	8 LB	WATER		G25	L FOLIAR	.	0	7	12	.	14
KRENITE	8 LB	WATER		G25	FALL	.	2	5	0	.	14
(TORDON K +	1 LB					.	.	.	.	.	
2,4-D ESTER)	4 LB	WATER		10	E FOLIAR	.	.	90	.	.	39
ROUNDUP	1 LB	WATER		S7	E FOLIAR	20	.	.	.	0P	53B
ROUNDUP	1 LB	WATER		S10	E FOLIAR	20	.	.	.	0P	53C
ROUNDUP	4 LB	WATER		G25	E FOLIAR	.	74	70	33	.	14
ROUNDUP	1 LB	WATER		10	L FOLIAR	.	0	0	0	1	16
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	40	.	.	.	2	58B
ROUNDUP	2 LB	WATER	1% SURFACT	S10	L FOLIAR	60	.	.	.	.	49
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	80	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	0	0	10	3	16
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	100	.	.	.	4	44C
ROUNDUP	4 LB	WATER		G25	L FOLIAR	.	32	60	0	.	14
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	.	40	.	.	0	42
ROUNDUP	3 LB	WATER		10	L SUMMER	.	10	.	.	.	52G

SNOWBRUSH (SLICK LEAF) CEANOTHUS (CEANOTHUS VELUTINUS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	30	.	.	.	52G
ROUNDUP	3 LB	WATER		10	L SUMMER	.	20	.	.	.	52W
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	20	.	.	.	52S
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	20	.	.	.	52S
ROUNDUP	4 LB	WATER	1% SURFACT	10	L SUMMER	.	40	.	.	.	52X
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER	1% SURFACT	10	L SUMMER	.	60	.	.	.	52X
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER		10	L SUMMER	.	60	.	.	.	52X
ROUNDUP	4 LB	WATER		G25	FALL	.	0	3	0	.	14
(ROUNDUP +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	5% R-11,TV	10	L SUMMER	.	20	.	.	6	43A
TORDON 101	2 GAL	WATER		10	E FOLIAR	.	.	85	.	.	39
VELPAR G	1.4 LB	GRANULE		G	L SUMMER	.	30	.	.	.	52S
(VELPAR +	1 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	20	.	4	43G
2,4-DP	2 LBHG	WATER	5% DIESEL	GDP	L FOLIAR	.	99	.	50	.	7

OCEANSPRAY (HOLODISCUS DISCOLOR)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	.	.	60	.	3	39
2,4-D ESTER	0.75 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	14	.	.	.	27
2,4-D ESTER	1.5 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	13	.	.	.	27
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	18	0	0	2	13
2,4-D ESTER	2 LB	WATER		10	E FOLIAR	.	.	80	.	3	39
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	48	.	.	.	27
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	67	50	44	2	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	24	0	0	3	13
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	20	.	.	52R
2,4-D ESTER	2 LB	WATER		10	L SUMMER	.	.	80	.	2	39
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	23	18	0	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	.	34	0	0	3	13
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	.	81	.	.	.	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	.	100	.	100	.	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	.	32	.	0	.	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	.	82	.	.	.	32
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	20	.	.	52R
GARLON 4	1 LB	OIL		10	DORMANT	.	60	.	.	1	39
GARLON 4	2 LB	OIL		10	DORMANT	.	.	75	.	.	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	.	.	75	.	3	39
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	64	0	17	5	13
GARLON 4	1 LB	OIL		10	E FOLIAR	.	60	.	.	2	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	88	75	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	92	74	60	5	13
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	60	.	.	.	5	44B
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	32	2	0	1	13
GARLON 4	1.5 LB	WATER		10	L SUMMER	.	.	80	.	3	39
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	69	34	0	2	13
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	79	22	0	3	13
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON K)	0.5 LB	WATER		10	E FOLIAR	.	.	95	.	.	39

OCEANSPRAY (HOLODISCUS DISCOLOR)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON 101)	1 GAL	WATER		10	E FOLIAR	.	.	95	.	.	39
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	0	.	.	52R
(TORDON K +	1 LB					.	.	.	.	.	
2,4-D ESTER)	4 LB	WATER		10	E FOLIAR	.	.	90	.	.	39
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	95	100	100	5	13
ROUNDUP	0.75 LB	WATER		7.5	L FOLIAR	.	26	29	31	1	16
ROUNDUP	0.3 LB	WATER		S1.5	L FOLIAR	40	.	.	.	0P	45
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	100	100	100	0	17
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	100	.	.	.	2	58B
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	100	100	100	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	60	.	.	52R
ROUNDUP	2 LB	WATER		10	L SUMMER	.	46	16	33	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	83	67	75	0	13
ROUNDUP	2 LB	WATER		10	L SUMMER	20	70	.	.	0	50B
ROUNDUP	2 LB	WATER		10	L SUMMER	25	95	.	.	0	50C
ROUNDUP	3 LB	WATER		10	L SUMMER	35	90	.	.	0	50D
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	.	100	.	.	0	42
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	90	.	.	.	52G
ROUNDUP	3 LB	WATER		10	L SUMMER	.	20	.	.	.	52V
(ROUNDUP +	2 LB					.	.	.	.	.	
GARLON 4)	1 LB	WATER		10	L SUMMER	.	23	1	9	0	13
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	79	72	60	.	13
TORDON 101	2 GAL	WATER		10	E FOLIAR	.	.	90	.	.	39
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	.	87	.	70	.	32
TORDON 101	1 GAL	WATER		10	L SUMMER	.	72	30	15	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	100	86	60	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	.	100	56	33	.	13
(TORDON 101 +	1.5 GAL	WATER				.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	95	98	71	.	13

RED TWINBERRY (LONICERA UTAHENSIS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	58	0	33	1	13
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	30	.	.	52R
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	0	.	.	.	2	51
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	58	58	67	1	22
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	10	.	.	.	52F
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	30	.	.	52R
GARLON 3A	3 LB	WATER		10	L SUMMER	.	0	.	0	0	20
(GARLON 3A +	3 LB					.	.	.	.	.	
ROUNDUP)	0.5 LB	WATER		10	L SUMMER	.	0	.	0	0	57A
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	50	60	60	1	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	64	71	71	1	13
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	.	.	1	19
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	.	.	1	19
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	2	20
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	44	90	79	2	22
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	73	30	0	2	13

RED TWINBERRY (LONICERA UTAHENSIS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(GARLON 4 +	3 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT MORACT	15	L FOLIAR	.	61	.	.	5	57B
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	17	2	22
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	20	.	.	52R
ROUNDUP	0.75 LB	WATER		7.5	L FOLIAR	.	9	1	0	1	16
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	58	74	90	3	16
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	50	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	75	100	100	3	16
ROUNDUP	1 LB	WATER		10	L SUMMER	.	34	92	53	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	50	36	27	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	100	96	75	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	75	71	63	0	13
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	80	.	.	.	52G
ROUNDUP	3 LB	WATER		10	L SUMMER	.	70	.	.	.	52T
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52U
ROUNDUP	3 LB	WATER		10	L SUMMER	.	50	.	.	.	52V
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52W
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	90	.	.	.	52S
TORDON 101	1 GAL	WATER		10	L SUMMER	.	30	0	10	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	64	69	57	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	.	0	0	13	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	19	0	20	.	13
VELPAR L	2 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19

FALSE HUCKLEBERRY (MENZIESIA FERRUGINEA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	2 LB	WATER	3 QT MORACT	15	L FOLIAR	.	34	.	.	3	57B
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	0	.	.	52R
(2,4-D +	2 LB					.	.	.	.	.	
2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	40*	.	4	43F
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	.	100	.	100	.	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	.	100	.	100	.	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	.	71	.	.	.	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	.	98	.	80	.	32
(GARLON 4 +	3 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT MORACT	15	L FOLIAR	.	46	.	.	5	57B
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	70	.	.	52R
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	20	.	.	1	43C
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	20	.	.	1	43D
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	80	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	30	.	.	.	52I
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	40	.	.	.	52I
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52U
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52V
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	.	100	.	100	.	32

PACHISTIMA (PACHISTIMA MYRSINITES)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	0	.	.	52R
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	0	.	.	.	2	51
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	0	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	0	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	0	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	0	.	.	.	52F
ATRAZINE	5 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52P
ATRAZINE	5 LB	WATER		S10	L FOLIAR	.	0	.	.	.	52Q
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52P
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	0	.	.	52R
GARLON 4	2 LB	WATER	1%NT,MORACT	10.6	L FOLIAR	0	.	.	.	2	44K
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	0	.	.	.	5	44B
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	14	0	10	2	20
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	2	20
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	17	2	22
GARLON 4	5 LB	WATER	3 QT DIESEL	10	L SUMMER	.	5	0	0	3	20
(GARLON 4 +	3 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT MORACT	15	L FOLIAR	.	23	.	.	5	57B
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	0	.	.	52R
ROUNDUP	2 LB	WATER	.5%FIRECHEM	G10	E FOLIAR	20	.	.	.	.	47
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52P
ROUNDUP	0.3 LB	WATER		S1.5	L FOLIAR	0	.	.	.	0P	45
ROUNDUP	1 LB	WATER		10	L FOLIAR	.	0	0	0	1	16
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	0	.	.	.	2	58B
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	0	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	0	0	0	3	16
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	0	.	.	.	4	44A
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	0	.	.	.	4	44C
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	.	0	.	.	0	50A
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	0	.	.	2	43B
ROUNDUP	3 LB	WATER	.6% R-11	10	L SUMMER	.	0	.	.	1	43J
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	.	0	.	.	0	42
ROUNDUP	3 LB	WATER		10	L SUMMER	.	10	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	10	.	.	.	52H
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	10	.	.	.	52H
ROUNDUP	3 LB	WATER		10	L SUMMER	.	0	.	.	.	52T
ROUNDUP	3 LB	WATER		10	L SUMMER	.	0	.	.	.	52V
ROUNDUP	3 LB	WATER		10	L SUMMER	.	10	.	.	.	52W
ROUNDUP	3 LB	WATER		S10	L FOLIAR	.	10	.	.	.	52Q
ROUNDUP	4 LB	WATER	1% SURFACT	10	L SUMMER	.	0	.	.	.	52X
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER	1% SURFACT	10	L SUMMER	.	10	.	.	.	52X
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER		10	L SUMMER	.	0	.	.	.	52X
(ROUNDUP +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	5%R-11,TV	10	L SUMMER	.	0	.	.	6	43A
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	.	.	0	.	31
TORDON 101	1 GAL	WATER	NT	15	L FOLIAR	.	40	.	13	.	15
(VELPAR +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	0	.	4	43E
(VELPAR +	1 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	0	.	4	43G

SYRINGA (PHILADEPHUS LEWISII)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	0.75 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	37	.	.	.	27
2,4-D ESTER	1.5 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	32	.	.	.	27
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	78	.	.	.	27
2,4-D ESTER	4 LB	WATER		10	L SUMMER	.	100	50	33	3	13
(ROUNDUP +	2 LB					.	.	.	.	.	
GARLON 4)	1 LB	WATER		10	L SUMMER	.	0	0	0	0	13
TORDON 101	1 GAL	WATER		10	L SUMMER	.	50	67	33	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	100	100	100	.	13

NINEBARK (PHYSOCARPUS MALVACEUS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	30	0	8	2	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	46	0	17	2	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	62	1	8	3	13
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	10	.	.	52R
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	60	.	.	.	2	51
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	1	22
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	10	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	0	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	20	.	.	.	52F
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	3	13
ATRAZINE	10 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52L
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	40	.	.	.	52K
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52M
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	.	80	.	.	.	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	.	100	.	100	.	32
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	30	.	.	.	52L
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52M
DICAMBA	2 LB	WATER		GDP	L FOLIAR	.	70	.	.	.	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	.	88	.	70	.	32
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	60	.	.	52R
GARLON 3A	3 LB	WATER		10	L SUMMER	.	0	.	0	0	20
(GARLON 3A +	3 LB					.	.	.	.	.	
ROUNDUP)	0.5 LB	WATER		10	L SUMMER	.	0	.	0	0	57A
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	28	0	0	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	46	4	17	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	64	0	0	5	13
GARLON 4	2 LB	WATER	1%NT,MORACT	10.6	L FOLIAR	80	.	.	.	2	44K
GARLON 4	2 LB	WATER	3%NT,MORACT	10	L FOLIAR	100	.	.	.	2	44L
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	80	.	.	.	5	44B
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	.	.	1	19
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	1	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	3	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	.	.	1	19
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	9	2	22
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	41	0	0	2	13
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	37	0	14	3	13
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	2	22

NINEBARK (PHYSOCARPUS MALVACEUS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	2	22
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	10	.	.	52R
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	0	0	0	5	13
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	100	.	.	.	52L
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	50	.	.	.	52M
ROUNDUP	0.75 LB	WATER		7.5	L FOLIAR	.	0	0	0	1	16
ROUNDUP	0.3 LB	WATER		S1.5	L FOLIAR	40	.	.	.	0P	45
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	82	68	22	0	17
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	100	100	100	0	17
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	100	.	.	.	2	58B
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	37	26	18	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	85	83	67	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	43	62	25	3	16
ROUNDUP	2 LB	WATER	3% NT,DYE	10.6	L FOLIAR	80	.	.	.	2	44E
ROUNDUP	2 LB	WATER	3%	S	L FOLIAR	80	.	.	.	.	48
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	40	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	80	80	80	3	16
ROUNDUP	1 LB	WATER		10	L SUMMER	.	27	18	0	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	56	40	21	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	25	100	.	.	0	50C
ROUNDUP	3 LB	WATER		10	L SUMMER	30	95	.	.	0	50D
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	.	100	.	.	0	42
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	80	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	90	.	.	.	52S
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	90	.	.	.	52S
ROUNDUP	4 LB	WATER	1% SURFACT	10	L SUMMER	.	90	.	.	.	52X
(ROUNDUP +	2 LB					.	.	.	.	.	
GARLON 4)	1 LB	WATER		10	L SUMMER	.	19	0	0	0	13
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	40	9	11	.	13
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	.	86	.	70	.	32
TORDON 101	1 GAL	WATER		10	L SUMMER	.	30	0	0	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	93	79	67	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	.	100	97	75	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	.	96	43	17	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	88	50	10	.	13
VELPAR GB	10-20#	GRIDBAL			DORMANT	.	0	.	.	.	56
VELPAR L	2 LB	WATER		S10	E FOLIAR	.	60	.	.	.	52K
VELPAR G	2 LB	GRANULE		S	E FOLIAR	.	60	.	.	.	52K
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	70	.	.	.	52L
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	40	.	.	.	52M
VELPAR G	1.4 LB	GRANULE		G	L SUMMER	.	70	.	.	.	52S
VELPAR L	2 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
VELPAR G	2 LB	GRANULE		S	FALL	.	20	.	.	.	52B
VELPAR G	4 LB	GRANULE		S	FALL	.	70	.	.	.	52B

QUAKING ASPEN (POPULUS TREMULOIDES)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	20	.	.	52R
2,4-D ESTER	4 LB	WATER		G100	FALL	.	85	.	.	0	46A
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	40	.	.	52R
GARLON 3A	8 LB	WATER		G100	FALL	.	20	.	.	2	46A
(GARLON 3A +	2 LB					.	.	.	.	.	
TORDON 101)	4 LB	WATER		G100	FALL	.	50	.	.	2	46A
GARLON 4	4 LB	WATER		G100	FALL	.	30	.	.	2	46A
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	100	.	.	52R
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	.	100	.	.	0	50A

CHERRY (PRUNUS SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	.	.	50	.	3	39
2,4-D ESTER	0.75 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	6	.	.	.	27
2,4-D ESTER	1.5 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	13	.	.	.	27
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	40	.	.	.	27
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	40	.	.	.	2	51
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	40	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	40	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	30	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	50	.	.	.	52F
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	44	29	50	3	13
GARLON 3A	3 LB	WATER		10	L SUMMER	.	42	.	15	0	20
(GARLON 3A +	3 LB					.	.	.	.	.	
ROUNDUP)	0.5 LB	WATER		10	L SUMMER	.	19	.	63	0	57A
GARLON 4	1 LB	OIL		10	DORMANT	.	50	.	.	1	39
GARLON 4	2 LB	OIL		10	DORMANT	.	.	60	.	.	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	.	.	60	.	3	39
GARLON 4	1 LB	OIL		10	E FOLIAR	.	40	.	.	2	39
GARLON 4	1.5LB	WATER		10	E FOLIAR	.	70	.	.	3	39
GARLON 4	2 LB	WATER	2 QT DIESEL	10	E FOLIAR	.	.	85	.	.	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L FOLIAR	.	0	0	31	2	17
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	56	48	33	1	13
GARLON 4	1.5 LB	WATER		10	L SUMMER	.	.	75	.	3	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	72	3	50	3	13
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON K)	0.5 LB	WATER		10	E FOLIAR	.	.	95	.	.	39
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON 101)	1 GAL	WATER		10	E FOLIAR	.	.	95	.	.	39
(TORDON K +	1 LB					.	.	.	.	.	
2,4-D ESTER)	4 LB	WATER		10	E FOLIAR	.	.	95	.	.	39
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	67	0	17	5	13
ROUNDUP	0.75 LB	WATER		7.5	L FOLIAR	.	100	100	100	1	16
ROUNDUP	1.5 LB	WATER	1% R-11	5	L FOLIAR	.	0	0	17	0	17
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	8	28	13	0	17
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	100	100	100	0	17
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	60	.	.	.	2	58B
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	6	13	27	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	85	87	71	0	17
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	86	100	100	3	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	20	29	40	0	16
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	93	100	100	0	13

CHERRY (PRUNUS SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	.	60	.	.	0	50A
ROUNDUP	3 LB	WATER		10	L SUMMER	.	80	.	.	.	52G
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52W
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	100	75	75	.	13
TORDON 101	2 GAL	WATER		10	E FOLIAR	.	.	90	.	.	39
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	80	100	100	.	13
(VELPAR +	1 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	40	.	4	43G

CASCARA BUCKTHORN (RHAMNUS PURSHIANA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	.	.	50	.	3	39
2,4-D ESTER	2 LB	WATER		10	L SUMMER	.	.	80	.	2	39
GARLON 4	1 LB	OIL		10	DORMANT	.	85	.	.	1	39
GARLON 4	2 LB	OIL		10	DORMANT	.	.	90	.	.	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	.	.	90	.	3	39
GARLON 4	1 LB	OIL		10	E FOLIAR	.	75	.	.	2	39
GARLON 4	1.5LB	WATER		10	E FOLIAR	.	90	.	.	3	39
GARLON 4	2 LB	WATER	2 QT DIESEL	10	E FOLIAR	.	.	90	.	.	39
GARLON 4	1.5 LB	WATER		10	L SUMMER	.	.	75	.	3	39
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON K)	0.5 LB	WATER		10	E FOLIAR	.	.	95	.	.	39
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON 101)	1 GAL	WATER		10	E FOLIAR	.	.	95	.	.	39
(TORDON K +	1 LB					.	.	.	.	.	
2,4-D ESTER)	4 LB	WATER		10	E FOLIAR	.	.	95	.	.	39
TORDON 101	2 GAL	WATER		10	E FOLIAR	.	.	90	.	.	39

CURRANT (RIBES SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	0.83 LB	WATER		D	E FOLIAR	.	0	.	0	.	25
2,4-D ESTER	0.42 LB	WATER		D	E FOLIAR	.	100	.	100	.	25
2,4-D ESTER	0.62 LB	WATER		D	E FOLIAR	.	99	.	94	.	25
2,4-D ESTER	0.83 LB	WATER		D	E FOLIAR	.	100	.	100	.	25
2,4-D ESTER	1.25 LB	WATER		D	E FOLIAR	.	60	.	75	.	25
2,4-D ESTER	1.67 LB	WATER		D	E FOLIAR	.	100	.	100	.	25
2,4-D ESTER	1.67 LB	WATER		D	E FOLIAR	.	0	.	0	.	25
2,4-D ESTER	1.25 LB	WATER		D	E FOLIAR	.	100	.	100	.	25
2,4-D ESTER	2.5 LB	WATER		D	E FOLIAR	.	100	.	100	.	25
2,4-D ESTER	2.5 LB	WATER		D	E FOLIAR	.	0	.	0	.	25
2,4-D ESTER	3.33 LB	WATER		D	E FOLIAR	.	0	.	0	.	25
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G15	E FOLIAR	.	30	.	0	.	23
2,4-D ESTER	0.83 LB	WATER		G	L FOLIAR	.	18	.	.	.	25
2,4-D ESTER	0.83 LB	WATER		D	L FOLIAR	.	38	.	20	.	25
2,4-D ESTER	0.42 LB	WATER		D	L FOLIAR	.	83	.	92	.	25
2,4-D ESTER	0.62 LB	WATER		D	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	0.83 LB	WATER		D	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	0.83 LB	WATER		G	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	1.25 LB	WATER		D	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	1.67 LB	WATER		D	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	2.5 LB	WATER		D	L FOLIAR	.	100	.	100	.	25

CURRANT (RIBES SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	2.5 LB	WATER		G	L FOLIAR	.	84	.	60	.	25
2,4-D ESTER	2.5 LB	WATER		D	L FOLIAR	.	42	.	20	.	25
2,4-D ESTER	2.5 LB	WATER		G	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	10	.	.	52R
2,4-D ESTER	4.2 LB	WATER		G	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	4.2 LB	WATER		D	L FOLIAR	.	95	.	80	.	25
2,4-D ESTER	4.2 LB	WATER		D	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	5.8 LB	WATER		G	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	5.8 LB	WATER		G	L FOLIAR	.	87	.	60	.	25
2,4-D ESTER	5.8 LB	WATER		D	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	7.5 LB	WATER		G	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	7.5 LB	WATER		D	L FOLIAR	.	100	.	100	.	25
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	40	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	50	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	30	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	40	.	.	.	52F
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	G15	L SUMMER	.	66	.	.	.	23
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G15	L SUMMER	.	40	.	.	.	23
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	17	.	.	1	57E
2,4-D ESTER	0.75 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	4	.	.	.	27
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	67	67	67	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	3	13
BK 800	1 GAL	WATER		G15	E FOLIAR	.	86	.	72	5	57D
BK 800	1.5 GAL	WATER		G15	E FOLIAR	.	90	.	89	5	57D
BK 875	1 GAL	WATER		G15	E FOLIAR	.	54	.	40	5	57D
GARLON 4	2 LB	WATER	3 QT DIESEL	G15	E FOLIAR	.	76	.	50	.	23
GARLON 4	2 LB	WATER	3 QT DIESEL	G15	E FOLIAR	.	70	.	63	.	57D
GARLON 4	2 LB	DIESEL		G15	E FOLIAR	.	88	.	85	5	57D
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L FOLIAR	.	0	9	17	2	17
GARLON 4	2 LB	WATER	3 QT DIESEL	G15	L SUMMER	.	59	.	.	.	23
GARLON 4	2 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	49	.	.	4	57E
GARLON 4	5 LB	WATER	3 QT DIESEL	10	L SUMMER	.	97	96	60	3	20
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		G15	E FOLIAR	.	55	.	47	5	57D
(GARLON 4 +	1 LB										
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	28	.	.	3	57E
(GARLON 4 +	1 LB										
2,4-D ESTER)	1 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	29	.	.	2	57E
(GARLON 4 +	1.5 LB										
2,4-D ESTER)	1.5 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	55	.	.	3	57E
(GARLON 4 +	2 LB										
2,4-D ESTER)	1 LB	WATER	3 QT DIESEL	G10	L SUMMER	.	27	.	.	3	57E
(GARLON 4 +	1 LB										
TORDON K)	1 QT	WATER		G15	E FOLIAR	.	41	.	27	5	57D
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	0	.	.	52R
ROUNDUP	2 LB	WATER		G15	E FOLIAR	.	20	.	0	.	23
ROUNDUP	2 LB	WATER		G15	E FOLIAR	.	86	.	66	5	57D
ROUNDUP	2 LB	WATER	1% R-11	G15	E FOLIAR	.	78	.	37	5	57D
ROUNDUP	2 LB	WATER	2% R-11	G15	E FOLIAR	.	71	.	51	5	57D
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	15	28	15	5	13
ROUNDUP	0.3 LB	WATER		S1.5	L FOLIAR	40	.	.	.	0P	45
ROUNDUP	1 LB	WATER		10	L FOLIAR	.	0	45	0	1	16

CURRANT (RIBES SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	1.5 LB	WATER	1% R-11	5	L FOLIAR	.	0	0	0	0	17
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	0	0	0	0	17
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	0	0	14	0	17
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	100	.	.	.	2	58B
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	75	62	50	0	17
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	80	.	.	.	2	44D
ROUNDUP	2 LB	WATER	<1% NT	10.6	L FOLIAR	60	.	.	.	1	44G
ROUNDUP	2 LB	WATER	3%	S	L FOLIAR	80	.	.	.	.	48
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	30	.	.	52R
ROUNDUP	4 LB	WATER		G20	L FOLIAR	60	.	.	.	6	46B
ROUNDUP	1 LB	WATER		G15	L SUMMER	.	0	.	.	.	23
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	50	33	0	0	13
ROUNDUP	2 LB	WATER		G15	L SUMMER	.	47	.	.	.	23
ROUNDUP	3 LB	WATER		10	L SUMMER	.	30	.	.	.	52T
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52U
ROUNDUP	3 LB	WATER		10	L SUMMER	.	60	.	.	.	52V
ROUNDUP	3 LB	WATER		10	L SUMMER	.	80	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	80	.	.	.	52G
ROUNDUP	4 LB	WATER	1% SURFACT	10	L SUMMER	.	40	.	.	.	52X
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER	1% SURFACT	10	L SUMMER	.	40	.	.	.	52X
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER		10	L SUMMER	.	50	.	.	.	52X
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	13	17	0	.	13
TORDON 101	1 GAL	WATER		G15	E FOLIAR	.	25	.	15	5	57D
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	79	64	45	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	.	88	81	50	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		G15	E FOLIAR	.	68	.	51	5	57D
VELPAR L	2 LB	WATER		G15	E FOLIAR	.	0	.	5	5	57D
WEEDONE 170	3 QT	WATER		G15	E FOLIAR	.	41	.	7	.	23
WEEDONE 170	1 GAL	WATER		G15	E FOLIAR	.	48	.	26	5	57D
WEEDONE 170	3 QT	WATER	3 QT DIESEL	G15	L SUMMER	.	61	.	.	.	23
WEEDONE 170	6 QT	WATER	3 QT DIESEL	G15	L SUMMER	.	89	.	.	.	23

WILD ROSE (ROSA SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	15	21	13	2	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	17	21	25	2	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	52	1	33	3	13
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	30	.	.	52R
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	40	.	.	.	2	51
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	22	63	50	1	22
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	20	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	20	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	30	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	40	.	.	.	52F
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	67	76	40	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	.	29	35	13	3	13
ATRAZINE	10 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52L

WILD ROSE (ROSA SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52M
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52N
ATRAZINE	4 LB	WATER		S10	L SUMMER	.	10	.	.	.	52O
BK 800	1 GAL	WATER		G15	E FOLIAR	.	100	.	100	5	57D
BK 800	1.5 GAL	WATER		G15	E FOLIAR	.	100	.	100	5	57D
BK 875	1 GAL	WATER		G15	E FOLIAR	.	95	.	80	5	57D
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52L
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	30	.	.	.	52M
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52N
DALAPON	7.4 LB	WATER		S10	L SUMMER	.	10	.	.	.	52O
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	50	.	.	52R
GARLON 3A	3 LB	WATER		10	L SUMMER	.	60	.	0	0	20
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	93	73	53	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	92	81	44	5	13
GARLON 4	2 LB	DIESEL	G	15	E FOLIAR	.	100	.	67	5	57D
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	88	75	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L FOLIAR	.	58	0	33	2	17
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	68	.	.	1	19
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	87	75	1	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	80	67	67	3	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	87	.	.	1	19
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	64	90	83	2	22
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	77	66	53	2	13
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	89	75	40	3	13
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	83	65	75	2	22
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	38	100	100	2	22
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	0	.	.	52R
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	93	90	40	5	13
ROUNDUP	2 LB	WATER		S10	E FOLIAR	.	30	.	.	.	52N
ROUNDUP	2 LB	WATER		G15	E FOLIAR	.	78	.	33	5	57D
ROUNDUP	2 LB	WATER	1% R-11	G15	E FOLIAR	.	92	.	50	5	57D
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	80	.	.	.	52L
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52M
ROUNDUP	0.3 LB	WATER		S1.5	L FOLIAR	20	.	.	.	0P	45
ROUNDUP	1.5 LB	WATER	1% R-11	5	L FOLIAR	.	25	2	50	0	17
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	60	62	29	0	17
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	100	96	80	0	17
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	40	.	.	.	2	58B
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	45	40	31	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	78	93	86	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	100	100	100	3	16
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	.	20	.	.	.	40A
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	40	.	.	52R
ROUNDUP	2 LB	WATER		10	L SUMMER	.	26	0	0	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	15	0	8	0	13
ROUNDUP	2 LB	WATER		S10	L SUMMER	.	40	.	.	.	52O
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	90	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	100	.	.	.	52H
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	90	.	.	.	52H

WILD ROSE (ROSA SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	3 LB	WATER		10	L SUMMER	.	60	.	.	.	52T
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52V
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52W
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	90	.	.	.	52S
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	90	.	.	.	52S
ROUNDUP	4 LB	WATER	1% SURFACT	10	L SUMMER	.	100	.	.	.	52X
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER		10	L SUMMER	.	100	.	.	.	52X
(ROUNDUP +	2 LB					.	.	.	.	.	
GARLON 4)	1 LB	WATER		10	L SUMMER	.	45	0	9	0	13
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	.	.	100	.	31
TORDON 101	1 GAL	WATER		G15	E FOLIAR	.	100	.	100	5	57D
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	86	93	88	.	13
TORDON 101	1 GAL	WATER		10	L SUMMER	.	66	80	60	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	93	98	99	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	.	100	95	91	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	.	77	67	50	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	94	94	67	.	13
VELPAR L	2 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52N
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	70	.	.	.	52L
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	40	.	.	.	52M
VELPAR G	1.4 LB	GRANULE		G	L SUMMER	.	70	.	.	.	52S
VELPAR L	2 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
VELPAR L	2 LB	WATER		S10	L SUMMER	.	30	.	.	.	52O
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
(VELPAR +	1 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	20	.	4	43G

THIMBLEBERRY (RUBUS PARVIFLORUS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	0	0	0	2	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	0	0	9	2	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	0	0	0	3	13
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	10	.	.	52R
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	33	1	22
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	30	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	20	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	30	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	30	.	.	.	52F
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	3	13
(2,4-D +	2 LB					.	.	.	.	.	
2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	0*	.	4	43F
(2,4-DP +	1 LBHG					.	.	.	.	.	
DICAMBA)	1 LBHG	DIESEL		GDP	DORMANT	.	100	.	10	.	35
AMITROL	1 LBHG	WATER		GDP	E FOLIAR	.	84	.	10	.	33
AMITROL	3 LBHG	WATER		GDP	E FOLIAR	.	90	.	20	.	33
AMITROL	1 LBHG	WATER		GDP	L FOLIAR	.	51	.	0	.	33
AMITROL	3 LBHG	WATER		GDP	L FOLIAR	.	80	.	0	.	33

THIMBLEBERRY (RUBUS PARVIFLORUS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(2,4-D +	1 LBHG					.	.	.	.	.	
DICAMBA)	1 LBHG	DIESEL		GDP	DORMANT	.	100	.	0	.	35
DICAMBA	1 LBHG	DIESEL		GDP	DORMANT	.	100	.	0	.	35
DICAMBA	1 LBHG	WATER		GDP	E FOLIAR	.	81	.	0	.	33
DICAMBA	3 LBHG	WATER		GDP	E FOLIAR	.	76	.	20	.	33
DICAMBA	1 LBHG	WATER		GDP	L FOLIAR	.	59	.	0	.	33
DICAMBA	3 LBHG	WATER		GDP	L FOLIAR	.	92	.	0	.	33
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	10	.	.	52R
GARLON 3A	0.75 LB	WATER		G16	L SUMMER	.	67	.	.	.	57C
GARLON 3A	1.5 LB	WATER		G16	L SUMMER	.	79	.	.	.	57C
GARLON 3A	3 LB	WATER		10	L SUMMER	.	0	.	0	0	20
GARLON 3A	4.5 LB	WATER		G16	L SUMMER	.	45	.	.	.	57C
(GARLON 3A +	3 LB					.	.	.	.	.	
ROUNDUP)	0.5 LB	WATER		10	L SUMMER	.	75	.	50	0	57A
GARLON 4	1 LB	OIL		10	DORMANT	.	40	.	.	1	39
GARLON 4	2 LB	OIL		10	DORMANT	.	.	50	.	.	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	.	.	50	.	3	39
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	0	0	8	5	13
GARLON 4	1 LB	OIL		10	E FOLIAR	.	55	.	.	2	39
GARLON 4	1.5 LB	WATER		10	E FOLIAR	.	70	.	.	3	39
GARLON 4	1.5 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	65	.	.	.	18
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	0	0	38	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	G15	E FOLIAR	.	40	0	25	5	57D
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	47	7	24	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	33	.	.	.	18
GARLON 4	4.5 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	80	.	.	.	18
GARLON 4	1.5 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	98	.	.	.	18
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L FOLIAR	.	0	0	0	2	17
GARLON 4	3 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	100	.	.	.	18
GARLON 4	4.5 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	69	.	.	.	18
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	.	.	1	19
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	1	13
GARLON 4	1.5 LB	WATER		10	L SUMMER	.	.	60	.	3	39
GARLON 4	1.5 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	0	.	.	.	18
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	3	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	.	.	1	19
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	66	66	38	2	20
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	3	2	6	2	20
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	12	2	22
GARLON 4	3 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	42	.	.	.	18
GARLON 4	4.5 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	80	.	.	.	18
GARLON 4	5 LB	WATER	3 QT DIESEL	10	L SUMMER	.	54	26	53	3	20
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	0	0	0	2	13
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	0	0	0	3	13
(GARLON 4 +	3 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT MORACT	15	L FOLIAR	.	37	.	.	5	57B
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	2	22
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	2	22
(GARLON 4 +	1 LB					.	.	.	.	.	
TORDON K)	1 QT	WATER		G15	E FOLIAR	.	75	.	60	5	57D

THIMBLEBERRY (RUBUS PARVIFLORUS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON K)	0.5 LB	WATER		10	E FOLIAR	.	.	90	.	.	39
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON 101)	1 GAL	WATER		10	E FOLIAR	.	.	90	.	.	39
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	0	.	.	52R
PICLORAM	1 LBHG	WATER		GDP	E FOLIAR	.	100	.	70	.	33
PICLORAM	1 LBHG	WATER		GDP	L FOLIAR	.	100	.	80	.	33
TORDON 10K	10 LB	GRANULE		G	L FOLIAR	.	40	.	.	.	8
TORDON 10K	30 LB	GRANULE		G	L FOLIAR	.	40	.	.	.	8
(TORDON K +	1 LB					.	.	.	.	.	
2,4-D ESTER)	4 LB	WATER		10	E FOLIAR	.	.	90	.	.	39
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	73	60	47	5	13
ROUNDUP	2 LB	WATER		G15	E FOLIAR	.	38	.	25	5	57D
ROUNDUP	2 LB	WATER	1% R-11	G15	E FOLIAR	.	70	.	40	5	57D
ROUNDUP	2 LB	WATER	2% R-11	G15	E FOLIAR	.	6	.	25	5	57D
ROUNDUP	0.75 LB	WATER		7.5	L FOLIAR	.	38	49	27	1	16
ROUNDUP	1 LB	WATER		10	L FOLIAR	.	99	89	92	1	16
ROUNDUP	1.5 LB	WATER	1% R-11	5	L FOLIAR	.	8	0	23	0	17
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	90	86	63	0	17
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	85	90	60	0	17
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	54	44	42	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	88	95	82	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	100	100	100	3	16
ROUNDUP	2 LB	WATER	3% NT,DYE	10.6	L FOLIAR	100	.	.	.	2	44E
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	40	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	100	100	100	3	16
ROUNDUP	1 LB	WATER		10	L SUMMER	.	81	92	89	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	64	89	86	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	75	41	31	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	60	19	11	0	13
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	.	80	.	.	0	50A
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	20	.	.	2	43B
ROUNDUP	2 LB	WATER		10	L SUMMER	25	85	.	.	0	50B
ROUNDUP	2 LB	WATER		10	L SUMMER	25	75	.	.	0	50C
ROUNDUP	3 LB	WATER		10	L SUMMER	30	95	.	.	0	50D
ROUNDUP	3 LB	WATER	.6% R-11	10	L SUMMER	.	20	.	.	1	43J
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	70	.	.	.	52G
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	100	.	.	.	52H
ROUNDUP	3 LB	WATER		10	L SUMMER	.	40	.	.	.	52V
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER	1% SURFACT	10	L SUMMER	.	40	.	.	.	52X
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER		10	L SUMMER	.	60	.	.	.	52X
(ROUNDUP +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	5% R-11,TV	10	L SUMMER	.	0	.	.	6	43A
(ROUNDUP +	2 LB					.	.	.	.	.	
GARLON 4)	1 LB	WATER		10	L SUMMER	.	41	0	9	0	13
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	0	0	23	.	13
TORDON 101	1 GAL	WATER		G15	E FOLIAR	.	0	.	25	5	57D
TORDON 101	1 GAL	WATER		10	L SUMMER	.	68	0	21	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	24	0	67	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		G15	E FOLIAR	.	74	.	80	5	57D

THIMBLEBERRY (RUBUS PARVIFLORUS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	.	73	80	71	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	.	76	0	5	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	83	6	13	.	13
VELPAR L	2 LB	WATER		G15	E FOLIAR	.	54	.	40	5	57D
VELPAR L	2 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
(VELPAR +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	0	.	4	43E
(VELPAR +	1 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	0	.	4	43G
2,4-DP	1 LBHG	DIESEL		GDP	DORMANT	.	100	.	0	.	35
WEEDONE 170	2 QT	DIESEL		GDP	DORMANT	.	100	.	0	.	35
WEEDONE 170	2 QT	WATER		GDP	E FOLIAR	.	90	.	20	.	33
WEEDONE 170	1 GAL	WATER		G15	E FOLIAR	.	0	.	0	5	57D
WEEDONE 170	2 QT	WATER		GDP	L FOLIAR	.	87	.	10	.	33
WEEDONE 170	3 QT	WATER	3 QT DIESEL	G15	L SUMMER	.	0	.	.	.	23
WEEDONE 170	6 QT	WATER	3 QT DIESEL	G15	L SUMMER	.	0	.	.	.	23

TRAILING BLACKBERRY (RUBUS SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	1 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	45	.	.	.	57C
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	62	.	.	.	57C
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	0	0	0	3	13
2,4-D ESTER	1 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	70	.	.	.	57C
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	39	.	.	.	57C
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	72	.	.	.	57C
2,4-D ESTER	1 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	87	.	.	.	57C
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	94	.	.	.	57C
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	49	0	21	1	22
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	50	0	33	3	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	58	.	.	.	57C
GARLON 3A	0.75 LB	WATER		G16	L SUMMER	.	84	.	.	.	57C
GARLON 3A	1.5 LB	WATER		G16	L SUMMER	.	55	.	.	.	57C
GARLON 3A	4.5 LB	WATER		G16	L SUMMER	.	100	.	.	.	57C
GARLON 4	1.5 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	83	.	.	.	18
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	60	20	40	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	30	70	60	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	94	.	.	.	18
GARLON 4	4.5 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	99	.	.	.	18
GARLON 4	1.5 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	98	.	.	.	18
GARLON 4	3 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	99	.	.	.	18
GARLON 4	4.5 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	98	.	.	.	18
GARLON 4	1.5 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	98	.	.	.	18
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	100	100	3	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	100	100	2	22
GARLON 4	3 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	98	.	.	.	18
GARLON 4	4.5 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	99	.	.	.	18
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	42	48	40	2	22

TRAILING BLACKBERRY (RUBUS SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	0	0	0	0	17
ROUNDUP	1.5 LB	WATER		5	L FOLIAR	.	0	0	0	0	57D
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	0	0	12	0	17
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	0	0	0	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	75	36	40	0	17
ROUNDUP	3 LB	WATER		10	L SUMMER	.	30	.	.	.	52T
ROUNDUP	3 LB	WATER		10	L SUMMER	.	20	.	.	.	52U
ROUNDUP	3 LB	WATER		10	L SUMMER	.	70	.	.	.	52W
(ROUNDUP +	2 LB					.	.	.	.	.	
GARLON 4)	1 LB	WATER		10	L SUMMER	.	17	0	0	0	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	0	0	17	.	13

UPLAND WILLOW (SALIX SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	.	.	50	.	3	39
2,4-D ESTER	0.75 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	14	.	.	.	27
2,4-D ESTER	1.5 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	0	.	.	.	27
2,4-D ESTER	2 LB	WATER		10	E FOLIAR	.	.	70	.	3	39
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	7.5	E FOLIAR	.	31	.	.	.	27
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	40	.	.	52R
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	80	.	.	.	2	51
2,4-D ESTER	2 LB	WATER		10	L SUMMER	.	.	65	.	2	39
(2,4-D +	2 LB					.	.	.	.	.	
2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	40*	.	4	43F
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	.	98	.	80	.	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	.	93	.	80	.	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	.	80	.	60	.	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	.	100	.	100	.	32
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	30	.	.	52R
GARLON 3A	3 LB	WATER		10	L SUMMER	.	0	.	0	0	20
GARLON 4	2 LB	OIL		10	DORMANT	.	.	85	.	.	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	.	.	85	.	3	39
GARLON 4	1 LB	OIL		10	E FOLIAR	.	70	.	.	2	39
GARLON 4	1.5LB	WATER		10	E FOLIAR	.	80	.	.	3	39
GARLON 4	2 LB	WATER	2 QT DIESEL	10	E FOLIAR	.	.	85	.	.	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L FOLIAR	.	58	42	50	2	17
GARLON 4	2 LB	WATER	1%NT,MORACT	10.6	L FOLIAR	40	.	.	.	2	44K
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	60	.	.	.	5	44B
GARLON 4	1.5 LB	WATER		10	L SUMMER	.	.	70	.	3	39
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	100	100	2	13
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON K)	0.5 LB	WATER		10	E FOLIAR	.	.	90	.	.	39
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON 101)	1 GAL	WATER		10	E FOLIAR	.	.	90	.	.	39
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	20	.	.	52R
(TORDON K +	1 LB					.	.	.	.	.	
2,4-D ESTER)	4 LB	WATER		10	E FOLIAR	.	.	90	.	.	39
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	61	58	25	5	13
ROUNDUP	1.5 LB	WATER	1% R-11	5	L FOLIAR	.	0	0	27	0	17
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	55	3	33	0	17

UPLAND WILLOW (SALIX SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	80	67	64	0	17
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	21	16	33	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	100	100	100	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	18	49	33	3	16
ROUNDUP	2 LB	WATER	<1% NT	10.6	L FOLIAR	60	.	.	.	1	44G
ROUNDUP	2 LB	WATER	3%	S	L FOLIAR	100	.	.	.	.	48
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	60	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	55	26	40	3	16
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	60	.	.	.	4	44A
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	60	.	.	.	4	44C
ROUNDUP	1 LB	WATER		10	L SUMMER	.	2	0	0	0	16
ROUNDUP	2 LB	WATER		G15	L SUMMER	.	100	.	.	.	23
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	.	80	.	.	0	50A
ROUNDUP	2 LB	WATER		10	L SUMMER	15	100	.	.	0	50B
ROUNDUP	2 LB	WATER		10	L SUMMER	15	80	.	.	0	50C
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	2	43B
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43C
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43D
ROUNDUP	2 LB	WATER		10.5	L SUMMER	.	80	.	.	0	62A
ROUNDUP	2 LB	WATER		10.5	L SUMMER	.	40	.	.	0	62B
ROUNDUP	2 LB	WATER		10.5	L SUMMER	.	100	.	.	0	62C
ROUNDUP	2 LB	WATER		10.5	L SUMMER	.	20	.	.	0	62D
ROUNDUP	2 LB	WATER		10.5	L SUMMER	.	80	.	.	0	62E
ROUNDUP	2 LB	WATER		10.5	L SUMMER	.	20	.	.	0	62F
ROUNDUP	3 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43J
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	.	100	.	.	0	42
ROUNDUP	3 LB	WATER		10	L SUMMER	25	15	.	.	0	50D
ROUNDUP	3 LB	WATER		10	L SUMMER	.	50	.	.	.	52T
ROUNDUP	3 LB	WATER		10	L SUMMER	.	80	.	.	.	52U
ROUNDUP	3 LB	WATER		10	L SUMMER	.	60	.	.	.	52V
ROUNDUP	3 LB	WATER		10	L SUMMER	.	80	.	.	.	52W
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	90	.	.	.	52G
(ROUNDUP +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	5% R-11,TV	10	L SUMMER	.	40	.	.	6	43A
TORDON 101	2 GAL	WATER		10	E FOLIAR	.	.	85	.	.	39
TORDON 101	1 GAL	WATER	NT	15	L FOLIAR	.	95	.	63	.	15
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	.	79	.	.	.	32
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	83	33	33	.	13
VELPAR GB	10-20/	GRIDBAL			L SUMMER	.	80	.	.	.	55
VELPAR GB	10-20#	GRIDBAL			DORMANT	.	0	.	.	.	56
VELPAR GB	1-8SHRUB	GRIDBAL			E FOLIAR	0	.	.	.	.	55
(VELPAR +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	20	.	4	43E
(VELPAR +	1 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	20	.	4	43G

ELDERBERRY (SAMBUCUS SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	.	.	60	.	3	39

ELDERBERRY (SAMBUCUS SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	2 LB	WATER		10	E FOLIAR	.	.	80	.	3	39
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	G15	L SUMMER	.	100	.	.	.	23
2,4-D ESTER	2 LB	WATER		10	L SUMMER	.	.	70	.	2	39
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	70	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	100	.	.	.	52F
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G15	L SUMMER	.	100	.	.	.	23
GARLON 3A	3 LB	WATER		10	L SUMMER	.	59	.	12	0	20
(GARLON 3A +	3 LB					.	.	.	.	.	
ROUNDUP)	0.5 LB	WATER		10	L SUMMER	.	97	.	0	0	57A
GARLON 4	1 LB	OIL		10	DORMANT	.	40	.	.	1	39
GARLON 4	2 LB	OIL		10	DORMANT	.	.	60	.	.	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	.	.	60	.	3	39
GARLON 4	1 LB	OIL		10	E FOLIAR	.	80	.	.	2	39
GARLON 4	1.5LB	WATER		10	E FOLIAR	.	90	.	.	3	39
GARLON 4	2 LB	WATER	2 QT DIESEL	10	E FOLIAR	.	.	95	.	.	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L FOLIAR	.	93	91	69	2	17
GARLON 4	1.5 LB	WATER		10	L SUMMER	.	.	85	.	3	39
GARLON 4	2 LB	WATER	3 QT DIESEL	G15	L SUMMER	.	100	.	.	.	23
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON K)	0.5 LB	WATER		10	E FOLIAR	.	.	95	.	.	39
(GARLON 4 +	2 LB					.	.	.	.	.	
TORDON 101)	1 GAL	WATER		10	E FOLIAR	.	.	95	.	.	39
(TORDON K +	1 LB					.	.	.	.	.	
2,4-D ESTER)	4 LB	WATER		10	E FOLIAR	.	.	95	.	.	39
ROUNDUP	0.75 LB	WATER		7.5	L FOLIAR	.	94	65	33	1	16
ROUNDUP	1.5 LB	WATER	1% R-11	5	L FOLIAR	.	100	85	78	0	17
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	100	99	91	0	17
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	90	90	80	0	17
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	100	.	.	.	2	58B
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	100	100	100	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	99	100	100	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	93	100	100	3	16
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	90	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	100	100	100	3	16
ROUNDUP	1 LB	WATER		G15	L SUMMER	.	100	.	.	.	23
ROUNDUP	1 LB	WATER		10	L SUMMER	.	78	78	33	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	81	81	80	0	16
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	.	80	.	.	0	50A
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	80	.	.	.	52G
TORDON 101	2 GAL	WATER		10	E FOLIAR	.	.	95	.	.	39
(VELPAR +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	20	.	4	43E

MOUNTAIN ASH (SORBUS SCOPULINA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(GARLON 4 +	3 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT MORACT	15	L FOLIAR	.	30	.	.	5	57B
ROUNDUP	3 LB	WATER		10	L SUMMER	.	80	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	40	.	.	.	52G
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	.	.	90	.	31

SPIREA (SPIREA BETULAFOLIA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	55	.	20	2	13
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	10	.	.	52R
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	0	.	.	.	2	51
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	10	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	10	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	20	.	.	.	52F
ATRAZINE	10 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52L
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52L
DALAPON	7.4 LB	WATER		S10	L SUMMER	.	20	.	.	.	52O
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	10	.	.	52R
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	77	.	20	5	13
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	.	.	1	19
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	31	.	.	1	19
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	33	2	22
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	38	47	42	2	22
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	0	.	.	52R
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	100	.	.	.	52L
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	100	.	.	.	2	58B
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	20	.	.	52R
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	80	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	100	.	.	.	52H
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	100	.	.	.	52H
ROUNDUP	3 LB	WATER		10	L SUMMER	.	40	.	.	.	52T
ROUNDUP	3 LB	WATER		10	L SUMMER	.	80	.	.	.	52W
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	90	.	.	.	52S
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	100	.	.	.	52S
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	.	.	93	.	31
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	83	.	57	.	13
VELPAR GB	10-20#	GRIDBAL			DORMANT	.	0	.	.	.	56
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	100	.	.	.	52L
VELPAR G	1.4 LB	GRANULE		G	L SUMMER	.	80	.	.	.	52S
VELPAR L	2 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	.	58	.	.	1	19

SNOWBERRY (SYMPHORICARPOS SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	55	61	0	2	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	63	58	0	2	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	56	45	0	3	13
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	20	.	.	52R
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	20	.	.	.	2	51
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	27	15	0	1	22
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	G15	L SUMMER	.	0	.	.	.	23
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G15	L SUMMER	.	7	.	.	.	23
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	54	40	0	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	.	57	39	0	3	13
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52M
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52N
ATRAZINE	4 LB	WATER		S10	L SUMMER	.	10	.	.	.	52O

SNOWBERRY (SYMPHORICARPOS SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
BK 800	1 GAL	WATER		G15	E FOLIAR	.	100	.	75	5	57D
BK 800	1.5 GAL	WATER		G15	E FOLIAR	.	100	.	100	5	57D
BK 875	1 GAL	WATER		G15	E FOLIAR	.	83	.	20	5	57D
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52M
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52N
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	30	.	.	52R
GARLON 3A	0.75 LB	WATER		G16	L SUMMER	.	59	.	.	.	57C
GARLON 3A	1.5 LB	WATER		G16	L SUMMER	.	90	.	.	.	57C
GARLON 3A	3 LB	WATER		10	L SUMMER	.	0	.	0	0	20
(GARLON 3A +	3 LB					.	.	.	.	.	
ROUNDUP)	0.5 LB	WATER		10	L SUMMER	.	27	.	13	0	57A
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	50	2	0	5	13
GARLON 4	1.5 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	48	.	.	.	18
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	12	60	0	5	13
GARLON 4	2 LB	DIESEL		G15	E FOLIAR	.	90	.	20	5	57D
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	56	23	0	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	68	.	.	.	18
GARLON 4	4.5 LB	WATER	3 QT DIESEL	G16	E FOLIAR	.	64	.	.	.	18
GARLON 4	1.5 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	33	.	.	.	18
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L FOLIAR	.	0	0	9	2	17
GARLON 4	3 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	0	.	.	.	18
GARLON 4	4.5 LB	WATER	3 QT DIESEL	G16	L FOLIAR	.	15	.	.	.	18
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	.	.	1	19
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	17	0	0	1	13
GARLON 4	1.5 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	0	.	.	.	18
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	3	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	.	.	1	19
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	28	0	0	2	22
GARLON 4	3 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	0	.	.	.	18
GARLON 4	4.5 LB	WATER	3 QT DIESEL	G16	L SUMMER	.	0	.	.	.	18
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	44	13	0	2	13
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER	3 QT DIESEL	G15	E FOLIAR	.	89	.	33	5	57D
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	53	18	0	3	13
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	6	2	22
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	0	0	0	2	22
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	10	.	.	52R
ROUNDUP	1 LB	WATER		S8	E FOLIAR	100	.	.	.	0P	53A
ROUNDUP	1 LB	WATER		S7	E FOLIAR	80	.	.	.	0P	53B
ROUNDUP	1 LB	WATER		S10	E FOLIAR	80	.	.	.	0P	53C
ROUNDUP	2 LB	WATER		10	E FOLIAR	.	92	85	50	5	13
ROUNDUP	2 LB	WATER		G15	E FOLIAR	.	100	.	100	5	57D
ROUNDUP	2 LB	WATER	1% R-11	G15	E FOLIAR	.	100	.	60	5	57D
ROUNDUP	2 LB	WATER	2% R-11	G15	E FOLIAR	.	100	.	100	5	57D
ROUNDUP	2 LB	WATER		S10	E FOLIAR	.	50	.	.	.	52N
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	30	.	.	.	52M
ROUNDUP	4 LB	WATER		S	E FOLIAR	80	.	.	.	0P	59A
ROUNDUP	0.75 LB	WATER		7.5	L FOLIAR	.	0	12	0	1	16
ROUNDUP	1.5 LB	WATER		S10	L FOLIAR	95	100	.	.	5	55

SNOWBERRY (SYMPHORICARPOS SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	1.5 LB	WATER	1% R-11	5	L FOLIAR	.	97	91	79	0	17
ROUNDUP	1.5 LB	WATER		7.5	L FOLIAR	.	94	89	60	0	17
ROUNDUP	1.5 LB	WATER		10	L FOLIAR	.	100	100	95	0	17
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	100	.	.	.	2	58B
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	.	75	56	28	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	100	100	100	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	99	100	100	3	16
ROUNDUP	2 LB	WATER	3%	S	L FOLIAR	100	.	.	.	.	48
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	.	40	.	.	.	40A
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	80	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	100	100	95	3	16
ROUNDUP	4 LB	WATER		G20	L FOLIAR	100	.	.	.	6	46B
ROUNDUP	1 LB	WATER		10	L SUMMER	.	98	100	83	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	88	87	75	0	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	85	91	47	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	94	98	71	0	13
ROUNDUP	2 LB	WATER		G15	L SUMMER	.	100	.	.	.	23
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	.	70	.	.	0	50A
ROUNDUP	2 LB	WATER		S10	L SUMMER	.	80	.	.	.	52O
ROUNDUP	2 LB	WATER		10	L SUMMER	25	100	.	.	0	50D
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	100	.	.	.	52H
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	100	.	.	.	52H
ROUNDUP	3 LB	WATER		10	L SUMMER	.	50	.	.	.	52T
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	100	.	.	.	52S
(ROUNDUP +	2 LB					.	.	.	.	.	
GARLON 4)	1 LB	WATER		10	L SUMMER	.	28	46	0	0	13
TORDON 101	1 GAL	WATER		10	E FOLIAR	.	51	22	0	.	13
TORDON 101	1 GAL	WATER		G15	E FOLIAR	.	100	.	80	5	57D
TORDON 101	1 GAL	WATER		10	L SUMMER	.	70	47	0	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	53	17	0	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	.	68	39	0	.	13
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	.	57	28	8	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	59	0	0	.	13
VELPAR G	2 LB	GRANULE		S	E FOLIAR	.	40	.	.		52M
VELPAR L	2 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52N
VELPAR L	2 LB	WATER		G15	E FOLIAR	.	73	.	25	5	57D
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	30	.	.	.	52M
VELPAR L	2 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
VELPAR L	2 LB	WATER		S10	L SUMMER	.	30	.	.	.	52M
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
WEEDONE 170	1 GAL	WATER		G15	L SUMMER	.	100	.	100	5	57D
WEEDONE 170	3 QT	WATER	3 QT DIESEL	G15	L SUMMER	.	0	.	.	.	23

HUCKLEBERRY (VACCINIUM SPP.)

2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	.	.	10	.	.	52R
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	40	.	.	.	2	51

HUCKLEBERRY (VACCINIUM SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	10	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	40	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	30	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	40	.	.	.	52F
2,4-D ESTER	4 LB	WATER		10	L SUMMER	.	58	59	60	3	13
BK 800	1 GAL	WATER		G15	E FOLIAR	.	100	.	100	5	57D
BK 800	1.5 GAL	WATER		G15	E FOLIAR	.	93	.	67	5	57D
BK 875	1 GAL	WATER		G15	E FOLIAR	.	60	.	25	5	57D
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	.	.	60	.	.	52R
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	91	92	75	5	13
GARLON 4	1 GAL	DIESEL		G15	E FOLIAR	.	76	.	0	0	57D
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	94	88	5	13
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	47	.	.	1	19
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	.	100	100	100	1	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	45	.	.	1	19
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	52	60	14	2	20
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	45	68	11	2	20
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	.	90	88	75	2	22
GARLON 4	5 LB	WATER	3 QT DIESEL	10	L SUMMER	.	77	73	27	3	20
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	91	59	13	2	13
(GARLON 4 +	2 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	.	100	96	67	3	13
(GARLON 4 +	3 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT MORACT	15	L FOLIAR	.	89	.	.	5	57B
(GARLON 4 +	1 LB					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	L SUMMER	.	21	58	67	2	22
KRENITE	2 LB	WATER		15	L FOLIAR	.	.	0	.	.	52R
ROUNDUP	4 LB	WATER		S	E FOLIAR	80	.	.	.	0P	59C
ROUNDUP	1 LB	WATER		10	L FOLIAR	.	23	31	4	1	16
ROUNDUP	1 LB	WATER		10	L FOLIAR	.	23	31	4	1	16
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	70	.	.	.	2	58B
ROUNDUP	2 LB	WATER		10	L FOLIAR	.	.	40	.	.	52R
ROUNDUP	3 LB	WATER		10	L FOLIAR	.	45	16	19	3	16
ROUNDUP	2 LB	WATER		10	L SUMMER	.	25	0	9	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	.	7	7	7	0	13
ROUNDUP	3 LB	WATER		10	L SUMMER	.	50	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	70	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	20	.	.	.	52I
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	20	.	.	.	52I
ROUNDUP	3 LB	WATER		10	L SUMMER	.	30	.	.	.	52T
ROUNDUP	3 LB	WATER		10	L SUMMER	.	80	.	.	.	52U
ROUNDUP	3 LB	WATER		10	L SUMMER	.	60	.	.	.	52V
ROUNDUP	3 LB	WATER		10	L SUMMER	.	60	.	.	.	52W
(ROUNDUP +	4 LB					.	.	.	.	.	
GARLON 3A)	0.33 LB	WATER		10	L SUMMER	.	30	.	.	.	52X
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	.	79	79	67	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	.	98	96	75	.	13

HUCKLEBERRY (VACCINIUM SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(TORDON 101 +	1 GAL					.	.	.	.	.	
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	.	67	39	33	.	13
(TORDON 101 +	1.5 GAL					.	.	.	.	.	
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	.	37	27	0	.	13
VELPAR L	4 LB	WATER		S100	L FOLIAR	.	100	.	.	0	41
VELPAR L	2 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	.	0	.	.	1	19

BRACKEN FERN (PTERIDIUM AQUILINUM)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	50	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	40	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	50	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	60	.	.	.	52F
ASULOX	.5 LB	WATER		G20	E FOLIAR	80	.	.	.	.	52Y
ASULOX	1 LB	WATER		G20	E FOLIAR	90	.	.	.	.	52Y
ASULOX	1 LB	WATER	.2% SURFACT	GDP	E FOLIAR	.	30	.	.	2	36
ASULOX	2 LB	WATER		G20	E FOLIAR	100	.	.	.	.	52Y
ASULOX	3 LB	WATER	.2% SURFACT	GDP	E FOLIAR	.	81	.	.	.	36
ASULOX	4 LB	WATER		G	E FOLIAR	.	0	0	.	.	38
ASULOX	1 LB	WATER	.2% SURFACT	GDP	L FOLIAR	.	87	.	.	1	36
ASULOX	2 LB	WATER	.2% SURFACT	GDP	L FOLIAR	.	91	.	.	1	36
ASULOX	3 LB	WATER	.2% SURFACT	GDP	L FOLIAR	.	94	.	.	.	36
ASULOX	3 LB	WATER	.2% CHIPCO	10	L FOLIAR	.	.	68	.	1	37
ASULOX	3.3 LB	WATER	.2% CHIPCO	10	L FOLIAR	.	.	91	.	1	37
ASULOX	3.3 LB	WATER		10	L FOLIAR	.	.	95	.	3	37
ASULOX	4 LB	WATER		G	L FOLIAR	.	92	95	.	.	38
ASULOX	6 LB	WATER	.2% CHIPCO	10	L FOLIAR	.	.	69	.	3	37
ASULOX	4 LB	WATER		G	L SUMMER	.	89	93	.	.	38
CASORON W50	4 LBHG	WATER		GDP	E FOLIAR	.	15	.	.	.	36
CASORON W50	8 LBHG	WATER		GDP	E FOLIAR	.	1	.	.	.	36
CASORON W50	4 LBHG	WATER		GDP	L FOLIAR	.	5	.	.	.	36
CASORON W50	8 LBHG	WATER		GDP	L FOLIAR	.	0	.	.	.	36
CASORON G-4	6 LB	GRANULE		G20	FALL	.	80	.	.	.	30
CASORON G-4	8 LB	GRANULE		G20	FALL	.	100	.	.	.	30
DICAMBA	4 LB	WATER		G20	DORMANT	.	60	.	.	.	30
DICAMBA	4 LBHG	WATER		GDP	E FOLIAR	.	95	.	.	.	36
DICAMBA	8 LB	WATER		G20	E FOLIAR	.	90	.	.	.	30
DICAMBA	8 LBHG	WATER		GDP	E FOLIAR	.	98	.	.	.	36
DICAMBA	4 LBHG	WATER		GDP	L FOLIAR	.	72	.	.	.	36
DICAMBA	4 LBHG	WATER	.2% SURFACT	GDP	L FOLIAR	.	37	.	.	.	36
DICAMBA	8 LBHG	WATER		GDP	L FOLIAR	.	98	.	.	.	36
TORDON 2K	2 LB	GRANULE		G	DORMANT	.	80	.	.	.	30
TORDON 2K	3 LB	GRANULE		G	DORMANT	.	100	.	.	.	30
PICLORAM	1 LBHG	WATER		GDP	E FOLIAR	.	20	.	.	.	36
TORDON K	2 LB	WATER		G20	E FOLIAR	.	90	.	.	.	30
PICLORAM	2 LBHG	WATER		GDP	E FOLIAR	.	45	.	.	.	36
TORDON K	3 LB	WATER		G20	E FOLIAR	.	100	.	.	.	30

BRACKEN FERN (PTERIDIUM AQUILINUM)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
TORDON K	4 LB	WATER		G20	E FOLIAR	.	100	.	.	.	30
PICLORAM	1 LBHG	WATER		GDP	L FOLIAR	.	66	.	.	.	36
PICLORAM	2 LBHG	WATER		GDP	L FOLIAR	.	82	.	.	.	36
TORDON 2K	2 LB	GRANULE		G	FALL	.	100	.	.	.	30
TORDON 2K	2 LB	GRANULE		G	FALL	.	94	73	.	.	30
TORDON 2K	2 LB	GRANULE		G	FALL	.	84	.	.	.	30
ROUNDUP	1 LB	WATER		G	L FOLIAR	.	79	63	.	.	38
ROUNDUP	2 LB	WATER		G	L FOLIAR	.	75	77	.	.	38
ROUNDUP	4 LB	WATER		G	L FOLIAR	.	95	97	.	.	38
ROUNDUP	6 LB	WATER		G	L FOLIAR	.	96	97	.	.	38
ROUNDUP	1 LB	WATER		G	L SUMMER	.	79	41	.	.	38
ROUNDUP	2 LB	WATER		G	L SUMMER	.	95	97	.	.	38
ROUNDUP	3 LB	WATER		10	L SUMMER	.	90	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	60	.	.	.	52G
ROUNDUP	3 LB	WATER		10	L SUMMER	.	100	.	.	.	52W
ROUNDUP	4 LB	WATER		G	L SUMMER	.	97	98	.	.	38
ROUNDUP	6 LB	WATER		G	L SUMMER	.	97	98	.	.	38

SWORD FERN (POLYSTICHUM MUNITUM)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
CASORON W50	4 LBHG	WATER		GDP	E FOLIAR	.	.	.	20	.	36
CASORON W50	8 LBHG	WATER		GDP	E FOLIAR	.	.	.	60	.	36
CASORON W50	4 LBHG	WATER		GDP	L FOLIAR	.	.	.	30	.	36
CASORON W50	8 LBHG	WATER		GDP	L FOLIAR	.	.	.	50	.	36
DICAMBA	1 LBHG	OIL		GDP	E FOLIAR	.	.	.	10	.	36
DICAMBA	1 LBHG	WATER		GDP	E FOLIAR	.	.	.	0	.	36
DICAMBA	2 LBHG	WATER		GDP	E FOLIAR	.	.	.	40	.	36
DICAMBA	3 LBHG	WATER		GDP	E FOLIAR	.	.	.	90	.	36
DICAMBA	4 LBHG	WATER		GDP	E FOLIAR	.	.	.	80	.	36
DICAMBA	8 LBHG	WATER		GDP	E FOLIAR	.	.	.	80	.	36
DICAMBA	4 LBHG	WATER		GDP	L FOLIAR	.	.	.	30	.	36
DICAMBA	8 LBHG	WATER		GDP	L FOLIAR	.	.	.	90	.	36
PICLORAM	1 LBHG	WATER		GDP	E FOLIAR	.	.	.	0	.	36
PICLORAM	2 LBHG	WATER		GDP	E FOLIAR	.	.	.	40	.	36
PICLORAM	1 LBHG	WATER		GDP	L FOLIAR	.	.	.	0	.	36
PICLORAM	2 LBHG	WATER		GDP	L FOLIAR	.	.	.	20	.	36

BEARGRASS (XEROPHYLLUM TENAX)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ASULOX	5 LB	WATER		G200	E FOLIAR	0	0	.	.	.	4
ATRAZINE	4 LB	WATER		G200	E FOLIAR	17	13	.	.	.	4
ATRAZINE	4 LB	WATER		G20	E FOLIAR	0	.	.	.	.	12
ATRAZINE	5 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52P
ATRAZINE	5 LB	WATER		S10	L FOLIAR	.	10	.	.	.	52Q
(DALAPON +	6 LB					.	.	.	.	.	
ATRAZINE)	3 LB	WATER		G200	E FOLIAR	23	30	.	.	.	4
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G200	E FOLIAR	30	33	.	.	.	4
(DALAPON +	8.5 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G20	E FOLIAR	0	.	.	.	.	12
(DALAPON +	10 LB					.	.	.	.	.	
ATRAZINE)	5 LB	WATER		G200	E FOLIAR	30	43	.	.	.	4
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52P

BEARGRASS (XEROPHYLLUM TENAX)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
DALAPON	8 LB	WATER		G200	E FOLIAR	30	27	.	.	.	4
DALAPON	8.5 LB	WATER		G20	E FOLIAR	16	.	.	.	.	12
DALAPON	7.4 LB	WATER		S10	L FOLIAR	.	10	.	.	.	52Q
ROUNDUP	1 LB	WATER		G20	E FOLIAR	0	.	.	.	.	12
ROUNDUP	2 LB	WATER		G20	E FOLIAR	33	.	.	.	.	12
ROUNDUP	2 LB	WATER		G200	E FOLIAR	7	20	.	.	.	4
ROUNDUP	2 LB	WATER	.5%FIRECHEM	G10	E FOLIAR	20	.	.	.	.	47
ROUNDUP	2 LB	WATER	1% SURFACT	S10	E FOLIAR	.	40	.	.	.	52C
ROUNDUP	3 LB	WATER		G20	E FOLIAR	42	.	.	.	.	12
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	60	.	.	.	52C
ROUNDUP	3 LB	WATER	1% SURFACT	S10	E FOLIAR	.	50	.	.	.	52C
ROUNDUP	3 LB	WATER	1% SURFACT	S10	E FOLIAR	.	40	.	.	.	52D
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52P
ROUNDUP	4 LB	WATER		G200	E FOLIAR	30	50	.	.	.	4
ROUNDUP	4 LB	WATER	1% SURFACT	S10	E FOLIAR	.	60	.	.	.	52C
ROUNDUP	2 LB	WATER	1% SURFACT	S10	L FOLIAR	.	30	.	.	.	52C
ROUNDUP	2 LB	WATER		S10	L FOLIAR	13	20	.	.	.	52A
ROUNDUP	3 LB	WATER		S10	L FOLIAR	.	20	.	.	.	52P
ROUNDUP	3 LB	WATER		S10	L FOLIAR	.	40	.	.	.	52C
ROUNDUP	3 LB	WATER	1% SURFACT	S10	L FOLIAR	.	40	.	.	.	52C
ROUNDUP	4 LB	WATER	1% SURFACT	S10	L FOLIAR	.	50	.	.	.	52C
ROUNDUP	4 LB	WATER		S10	L FOLIAR	40	30	.	.	.	52A
ROUNDUP	6 LB	WATER		S10	L FOLIAR	25	30	.	.	.	52A
ROUNDUP	8 LB	WATER		S10	L FOLIAR	.	40	.	.	.	52A
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	0	.	.	1	43C
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	0	.	.	1	43D
ROUNDUP	3 LB	WATER		10	L SUMMER	.	20	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	30	.	.	.	52I
ROUNDUP	3 LB	WATER		S10	L FOLIAR	.	30	.	.	.	52Q
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	40	.	.	.	52I
(ROUNDUP +	2 LB					.	.	.	.	.	
ATRAZINE)	2 LB	WATER		G20	E FOLIAR	21	.	.	.	.	12
(ROUNDUP +	3 LB					.	.	.	.	.	
GARLON4)	0.75 LB	WATER		S10	E FOLIAR	.	40	.	.	.	52C
(ROUNDUP +	3 LB					.	.	.	.	.	
GARLON4)	0.75 LB	WATER	1% SURFACT	S10	E FOLIAR	.	50	.	.	.	52C
(ROUNDUP +	3 LB					.	.	.	.	.	
GARLON4)	0.75 LB	WATER		S10	E FOLIAR	.	30	.	.	.	52D
(ROUNDUP +	3 LB					.	.	.	.	.	
GARLON4)	0.75 LB	WATER	1% SURFACT	S10	E FOLIAR	.	20	.	.	.	52D
(ROUNDUP +	3 LB					.	.	.	.	.	
GARLON4)	0.75 LB	WATER		S10	L FOLIAR	.	20	.	.	.	52C
(ROUNDUP +	3 LB					.	.	.	.	.	
GARLON 4	0.75 LB	WATER	1% SURFACT	S10	L FOLIAR	.	50	.	.	.	52C
(ROUNDUP +	1 QT					.	.	.	.	.	
VELPAR)	1 LB	WATER		G20	E FOLIAR	44	.	.	.	.	12
(ROUNDUP +	2 LB					.	.	.	.	.	
VELPAR)	2 LB	WATER		G20	E FOLIAR	26	.	.	.	.	12

BEARGRASS (XEROPHYLLUM TENAX)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
VELPAR L	1 LB	WATER		G200	E FOLIAR	33	30	.	.	.	4
VELPAR L	2 LB	WATER		G200	E FOLIAR	50	37	.	.	.	4
VELPAR L	2 LB	WATER		G20	E FOLIAR	37	.	.	.	.	12
VELPAR G	2 LB	GRANULE		S	E FOLIAR	.	80	.	.	.	52K
VELPAR L	3 LB	WATER		G200	E FOLIAR	50	50	.	.	.	4
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	30	.	.	.	52C
VELPAR L	3 LB	WATER	1% SURFACT	S10	E FOLIAR	.	50	.	.	.	52C
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	60	.	.	.	52D
VELPAR L	3 LB	WATER	1% SURFACT	S10	E FOLIAR	.	60	.	.	.	52D
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	40	.	.	.	52P
VELPAR L	4 LB	WATER		G200	E FOLIAR	53	47	.	.	.	4
VELPAR L	5 LB	WATER		S10	E FOLIAR	.	50	.	.	.	52C
VELPAR L	5 LB	WATER	1% SURFACT	S10	E FOLIAR	.	60	.	.	.	52C
VELPAR L	5 LB	WATER		S10	E FOLIAR	.	80	.	.	.	52D
VELPAR G	2 LB	GRANULE		S	L FOLIAR	73	70	.	.	.	52A
VELPAR L	2 LB	WATER		S10	L FOLIAR	50	47	.	.	.	52A
VELPAR L	3 LB	WATER		S10	L FOLIAR	.	40	.	.	.	52C
VELPAR L	3 LB	WATER	1% SURFACT	S10	L FOLIAR	.	60	.	.	.	52C
VELPAR L	3 LB	WATER		S10	L FOLIAR	.	50	.	.	.	52Q
VELPAR L	4 LB	WATER		S100	L FOLIAR	.	60	.	.	0	41
VELPAR G	4 LB	GRANULE		S	L FOLIAR	85	93	.	.	.	52A
VELPAR L	4 LB	WATER		S10	L FOLIAR	70	80	.	.	.	52A
VELPAR L	5 LB	WATER		S10	L FOLIAR	.	40	.	.	.	52C
VELPAR L	5 LB	WATER	1% SURFACT	S10	L FOLIAR	.	50	.	.	.	52C
VELPAR G	6 LB	GRANULE		S	L FOLIAR	75	87	.	.	.	52A
VELPAR L	6 LB	WATER		S10	L FOLIAR	82	100	.	.	.	52A
VELPAR G	8 LB	GRANULE		S	L FOLIAR	86	97	.	.	.	52A
VELPAR L	8 LB	WATER		S10	L FOLIAR	82	100	.	.	.	52A

SEDGES (CAREX SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(2,4-D +	4.2 LB					.	.	.	.	.	
DALAPON)	8 LBS	WATER	1PT SURFACT	S100	E FOLIAR	80	.	.	.	0P	61
ASULOX	5 LB	WATER		G200	E FOLIAR	0	0	.	.	.	4
ATRAZINE	10 LB	WATER		S10	E FOLIAR	.	30	.	.	.	52L
ATRAZINE	4 LB	WATER		G200	E FOLIAR	23	0	.	.	.	4
ATRAZINE	4 LB	WATER		G200	E FOLIAR	0	0	.	.	.	4
ATRAZINE	4 LB	WATER		G20	E FOLIAR	21	.	.	.	.	12
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	60	.	.	.	52K
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52M
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52N
ATRAZINE	5 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52P
ATRAZINE	5 LB	WATER		S10	L FOLIAR	.	20	.	.	.	52Q
ATRAZINE	4 LB	WATER		S10	L SUMMER	.	10	.	.	.	52O
(DALAPON +	6 LB					.	.	.	.	.	
ATRAZINE)	3 LB	WATER		G200	E FOLIAR	87	25	.	.	.	4
(DALAPON +	6 LB					.	.	.	.	.	
ATRAZINE)	3 LB	WATER		G200	E FOLIAR	83	57	.	.	.	4
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G200	E FOLIAR	85	35	.	.	.	4
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G200	E FOLIAR	100	75	.	.	.	4

SEDGES (CAREX SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(DALAPON + ATRAZINE)	8.5 LB 4 LB	WATER		G20	E FOLIAR	74	.	.	.	.	12
(DALAPON + ATRAZINE)	10 LB 5 LB	WATER		G200	E FOLIAR	90	47	.	.	.	4
(DALAPON + ATRAZINE)	10 LB 5 LB	WATER		G200	E FOLIAR	100	93	.	.	.	4
(ATRAZINE + DALAPON)	4 LB 8 LB	WATER	.1% NT	10	FALL	.	.	20*	.	.	43I
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	50	.	.	.	52L
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52M
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52N
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52P
DALAPON	8 LB	WATER		G200	E FOLIAR	77	10	.	.	.	4
DALAPON	8 LB	WATER		G200	E FOLIAR	47	37	.	.	.	4
DALAPON	8.5 LB	WATER		G20	E FOLIAR	52	.	.	.	.	12
DALAPON	7.4 LB	WATER		S10	L FOLIAR	.	40	.	.	.	52Q
DALAPON	7.4 LB	WATER		S10	L SUMMER	.	50	.	.	.	520
ROUNDUP	1 LB	WATER		G20	E FOLIAR	100	.	.	.	.	12
ROUNDUP	1 LB	WATER		S7	E FOLIAR	40	.	.	.	0P	53B
ROUNDUP	1 LB	WATER		S10	E FOLIAR	80	.	.	.	0P	53C
ROUNDUP	2 LB	WATER		G20	E FOLIAR	100	.	.	.	.	12
ROUNDUP	2 LB	WATER		G200	E FOLIAR	100	53	.	.	.	4
ROUNDUP	2 LB	WATER		G200	E FOLIAR	83	50	.	.	.	4
ROUNDUP	2 LB	WATER	.5% SURFACT	S25	E FOLIAR	70	.	.	.	0P	54A
ROUNDUP	2 LB	WATER		GDP	E FOLIAR	100	.	.	.	0P	53D
ROUNDUP	2 LB	WATER	.5% DYE	S3	E FOLIAR	60	.	.	.	0P	54B
ROUNDUP	2 LB	WATER		S10	E FOLIAR	.	50	.	.	.	52N
ROUNDUP	3 LB	WATER		G20	E FOLIAR	77	.	.	.	.	12
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	90	.	.	.	52L
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52M
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52P
ROUNDUP	4 LB	WATER		G200	E FOLIAR	100	90	.	.	.	4
ROUNDUP	4 LB	WATER		G200	E FOLIAR	100	63	.	.	.	4
ROUNDUP	4 LB	WATER		S	E FOLIAR	60	.	.	.	0P	59A
ROUNDUP	4 LB	WATER		S	E FOLIAR	80	.	.	.	0P	59D
ROUNDUP	4 LB	WATER		S	E FOLIAR	80	.	.	.	0P	59E
ROUNDUP	4 LB	WATER		S	E FOLIAR	60	.	.	.	0P	59F
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	80	.	.	.	2	58B
ROUNDUP	2 LB	WATER	3%	S	L FOLIAR	100	.	.	.	.	48
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	.	60	.	.	.	40A
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	100	.	.	.	.	40B
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	80	.	.	.	4	44A
ROUNDUP	3 LB	WATER		S10	L FOLIAR	.	30	.	.	.	52P
ROUNDUP	4 LB	WATER		S	L FOLIAR	80	.	.	.	0P	59B
ROUNDUP	0.25 LB	WATER		S6.6	L SUMMER	100	.	.	.	.	60
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43C
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43D
ROUNDUP	2 LB	WATER		S10	L SUMMER	.	60	.	.	.	520
ROUNDUP	3 LB	WATER		10	L SUMMER	.	40	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	60	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	70	.	.	.	52H
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	60	.	.	.	52H
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	10	.	.	.	52I
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	0	.	.	.	52I

SEDGES (CAREX SPP.)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ROUNDUP	3 LB	WATER		S10	L FOLIAR	.	30	.	.	.	52Q
ROUNDUP	3 LB	WATER		10	L SUMMER	.	30	.	.	.	52U
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	20	.	.	.	52S
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	50	.	.	.	52S
(ROUNDUP +	2 LB					.	.	.	.	.	
ATRAZINE)	2 LB	WATER		G20	E FOLIAR	100	.	.	.	.	12
(ROUNDUP +	1 QT					.	.	.	.	.	
VELPAR)	1 LB	WATER		G20	E FOLIAR	100	.	.	.	.	12
(ROUNDUP +	2 LB					.	.	.	.	.	
VELPAR)	2 LB	WATER		G20	E FOLIAR	100	.	.	.	.	12
VELPAR L	1 LB	WATER		G	DORMANT	60	.	.	.	.	28
VELPAR L	1 LB	WATER		G	DORMANT	50	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	DORMANT	87	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	DORMANT	62	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	80	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	93	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	75	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	100	.	.	.	.	28
VELPAR L	4 LB	WATER		G	DORMANT	100	.	.	.	.	28
VELPAR L	4 LB	WATER		G	DORMANT	93	.	.	.	.	28
VELPAR L	1 LB	WATER		G200	E FOLIAR	27	10	.	.	.	4
VELPAR L	1 LB	WATER		G200	E FOLIAR	47	0	.	.	.	4
VELPAR L	2 LB	WATER		G200	E FOLIAR	70	0	.	.	.	4
VELPAR L	2 LB	WATER		G200	E FOLIAR	60	40	.	.	.	4
VELPAR L	2 LB	WATER		G20	E FOLIAR	100	.	.	.	.	12
VELPAR L	2 LB	WATER		S10	E FOLIAR	.	90	.	.	.	52K
VELPAR G	2 LB	GRANULE		S	E FOLIAR	.	80	.	.		52K
VELPAR G	2 LB	GRANULE		S	E FOLIAR	.	10	.	.		52M
VELPAR L	2 LB	WATER		S10	E FOLIAR	.	70	.	.	.	52N
VELPAR L	3 LB	WATER		G200	E FOLIAR	77	25	.	.	.	4
VELPAR L	3 LB	WATER		G200	E FOLIAR	73	47	.	.	.	4
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	100	.	.	.	52L
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52M
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	50	.	.	.	52P
VELPAR L	4 LB	WATER		G200	E FOLIAR	87	20	.	.	.	4
VELPAR L	4 LB	WATER		G200	E FOLIAR	83	77	.	.	.	4
VELPAR L	3 LB	WATER		S10	L FOLIAR	.	70	.	.	.	52Q
VELPAR L	4 LB	WATER		S100	L FOLIAR	.	100	.	.	0	41
VELPAR G	1.4 LB	GRANULE		G	L SUMMER	.	80	.	.	.	52S
VELPAR L	2 LB	WATER		S10	L SUMMER	.	70	.	.	.	52O
VELPAR L	1 LB	WATER		G	FALL	12	.	.	.	.	28
VELPAR L	1 LB	WATER		G	FALL	0	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	FALL	93	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	FALL	50	.	.	.	.	28
VELPAR L	2 LB	WATER		G	FALL	100	.	.	.	.	28
VELPAR L	2 LB	WATER		G	FALL	83	.	.	.	.	28
VELPAR L	4 LB	WATER		G	FALL	100	.	.	.	.	28

GRASSES

2,4-D ESTER	1.5 LB	WATER		G	DORMANT	0	0	.	.	.	11
(2,4-D +	4.2 LB					.	.	.	.	.	
DALAPON)	8 LBS	WATER	1PT SURFACT	S100	E FOLIAR	20	.	.	.	0P	61

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ATRAZINE	3 LB	WATER		G100	DORMANT	63	8	.	.	3	10
ATRAZINE	4 LB	WATER		G200	DORMANT	2	.	.	.	.	34
ATRAZINE	4 LB	WATER		G100	DORMANT	85	10	.	.	3	10
ATRAZINE	4 LB	WATER		G	DORMANT	74	37	.	.	.	11
ATRAZINE	1 LB	WATER		G17	E FOLIAR	13	.	.	.	.	29
ATRAZINE	2 LB	WATER		G17	E FOLIAR	38	.	.	.	.	29
ATRAZINE	3 LB	WATER		G17	E FOLIAR	38	.	.	.	.	29
ATRAZINE	4 LB	WATER		G20	E FOLIAR	10	0	.	.	.	2
ATRAZINE	4 LB	WATER		G17	E FOLIAR	34	.	.	.	.	29
ATRAZINE	4 LB	WATER		G200	E FOLIAR	57	.	.	.	0	5
ATRAZINE	4 LB	WATER		G	E FOLIAR	23	.	.	.	0	5
ATRAZINE	4 LB	WATER		S10	E FOLIAR	60	.	.	.	.	52E
ATRAZINE	4 LB	WATER		S10	E FOLIAR	60	.	.	.	.	52J
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52M
(ATRAZINE +	3 LB					.	.	.	.	.	
2,4-D)	0.5 LB	WATFR		G100	DORMANT	70	5	.	.	1	10
(ATRAZINE +	4 LB					.	.	.	.	.	
2,4-D)	1.5 LB	WATER		G	DORMANT	75	20	.	.	.	11
(DALAPON +	4 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G10	DORMANT	40	10	.	.	.	1
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G	E FOLIAR	64	.	.	.	.	3
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G	E FOLIAR	94	.	.	.	.	3
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G	E FOLIAR	90	.	.	.	.	3
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER	.5% SURFACT	S	E FOLIAR	64	27	.	.	0	5
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER	.5% SURFACT	S	E FOLIAR	94	76	.	.	0	5
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER	.5% SURFACT	S	E FOLIAR	90	84	.	.	0	5
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER	.5% SURFACT	S	E FOLIAR	64	24	.	.	0	5
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G200	E FOLIAR	87	.	.	.	0	5
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G	E FOLIAR	70	.	.	.	0	5
(DALAPON +	4 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G10	FALL	25	0	.	.	.	1
(ATRAZINE +	4 LB					.	.	.	.	.	
DALAPON)	8 LB	WATER	.1% NT	10	FALL	.	.	20*	.	.	43I
CASORON W50	2 LB	WATER		G100	DORMANT	9	12	.	.	1	10
CASORON W50	4 LB	WATER		G100	DORMANT	14	7	.	.	2	10
CASORON W50	6 LB	WATER		G100	DORMANT	56	24	.	.	3	10
CASORON G-4	2 LB	GRANULE		G	DORMANT	30	12	.	.	2	10
CASORON G-4	4 LB	GRANULE		G	DORMANT	60	50	.	.	2	10
CASORON G-4	6 LB	GRANULE		G	DORMANT	65	52	.	.	3	10
DALAPON	13.6 LB	WATER		G100	DORMANT	80	28	.	.	3	10
DALAPON	5 LB	WATER		G200	DORMANT	78	.	.	.	.	34
DALAPON	6.8 LB	WATER		G100	DORMANT	69	21	.	.	1	10
DALAPON	12 LB	WATER		G	E FOLIAR	53	.	.	.	.	26
DALAPON	4 LB	WATER	.5% SURFACT	S	E FOLIAR	28	9	.	.	0	5
DALAPON	4 LB	WATER	.5% SURFACT	S	E FOLIAR	38	19	.	.	0	5

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
DALAPON	4 LB	WATER	.5% SURFACT	S	E FOLIAR	14	22	.	.	0	5
DALAPON	4 LB	WATER	.5% SURFACT	S	E FOLIAR	53	24	.	.	0	5
DALAPON	4 LB	WATER		G	E FOLIAR	52	.	.	.	.	26
DALAPON	4 LB	WATER		G	E FOLIAR	28	.	.	.	.	3
DALAPON	4 LB	WATER		G	E FOLIAR	38	.	.	.	.	3
DALAPON	4 LB	WATER		G	E FOLIAR	53	.	.	.	.	3
DALAPON	4 LB	WATER		G	E FOLIAR	14	.	.	.	.	3
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52M
DALAPON	8 LB	WATER		G	E FOLIAR	43	.	.	.	.	26
DALAPON	8 LB	WATER		G	E FOLIAR	47	.	.	.	.	3
DALAPON	8 LB	WATER		G	E FOLIAR	62	.	.	.	.	3
DALAPON	8 LB	WATER		G	E FOLIAR	32	.	.	.	.	3
DALAPON	8 LB	WATER	.5% SURFACT	S	E FOLIAR	47	28	.	.	0	5
DALAPON	8 LB	WATER	.5% SURFACT	S	E FOLIAR	62	27	.	.	0	5
DALAPON	8 LB	WATER	.5% SURFACT	S	E FOLIAR	32	32	.	.	0	5
DALAPON	8 LB	WATER	.5% SURFACT	S	E FOLIAR	62	24	.	.	0	5
DALAPON	8 LB	WATER		G200	E FOLIAR	50	.	.	.	0	5
DALAPON	8 LB	WATER		G	E FOLIAR	47	.	.	.	0	5
DALAPON	12 LB	WATER		G	L FOLIAR	18	.	.	.	.	26
DALAPON	4 LB	WATER		G	L FOLIAR	22	.	.	.	.	26
DALAPON	8 LB	WATER		G	L FOLIAR	20	.	.	.	.	26
ROUNDUP	2 LB	WATER		G48	DORMANT	92	.	.	.	.	24
ROUNDUP	1 LB	WATER		S8	E FOLIAR	100	.	.	.	0P	53A
ROUNDUP	1 LB	WATER		S7	E FOLIAR	100	.	.	.	0P	53B
ROUNDUP	2 LB	WATER	.5% SURFACT	S25	E FOLIAR	80	.	.	.	0P	54A
ROUNDUP	2 LB	WATER	.5% DYE	S3	E FOLIAR	80	.	.	.	0P	54B
ROUNDUP	2 LB	WATER		S10	E FOLIAR	80	.	.	.	0P	52E
ROUNDUP	2 LB	WATER		S10	E FOLIAR	40	.	.	.	.	52J
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52M
ROUNDUP	0.3 LB	WATER		S1.5	L FOLIAR	50	.	.	.	0P	45
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	100	.	.	.	2	58B
ROUNDUP	2 LB	WATER		G48	L FOLIAR	94	.	.	.	.	24
ROUNDUP	2 LB	WATER	3%	S	L FOLIAR	100	.	.	.	.	48
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	.	60	.	.	.	40A
ROUNDUP	2 LB	WATER	1% SURFACT	S10	L FOLIAR	100	.	.	.	.	49
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	100	.	.	.	.	40B
ROUNDUP	4 LB	WATER		G20	L FOLIAR	100	.	.	.	6	46B
ROUNDUP	1 LB	WATER		G15	L SUMMER	.	100	.	.	0	23
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	2	43B
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43C
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43D
ROUNDUP	3 LB	WATER	.6% R-11	10	L SUMMER	.	40	.	.	1	43J
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	60	.	.	.	52H
(ROUNDUP +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	5%R-11,TV	10	L SUMMER	.	20	.	.	6	43A
VELPAR L	1 LB	WATER		G	DORMANT	50	.	.	.	.	28
VELPAR L	1 LB	WATER		G	DORMANT	64	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	DORMANT	100	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	DORMANT	73	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	83	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	100	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	91	.	.	.	.	28
VELPAR L	2 LB	WATER		G20	DORMANT	75	50	.	.	.	1
VELPAR L	2 LB	WATER	.1% NT	10	DORMANT	.	.	40	.	.	43H

GRASSES

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
VELPAR L	4 LB	WATER		G	DORMANT	100	.	.	.	.	28
VELPAR L	1 LB	WATER		G17	E FOLIAR	50	.	.	.	.	29
VELPAR L	2 LB	WATER		G200	E FOLIAR	95	.	.	.	.	6
VELPAR L	2 LB	WATER		G17	E FOLIAR	83	.	.	.	.	29
VELPAR L	2 LB	WATER		S10	E FOLIAR	40	.	.	.	.	52E
VELPAR L	2 LB	WATER		S10	E FOLIAR	80	.	.	.	.	52J
VELPAR G	2 LB	GRANULE		S	E FOLIAR	.	20	.	.		52M
VELPAR L	3 LB	WATER		G17	E FOLIAR	91	.	.	.	.	29
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	30	.	.	.	52M
VELPAR L	4 LB	WATER		G17	E FOLIAR	94	.	.	.	.	29
VELPAR L	2 LB	WATER	2.2 %MORACT	10	L SUMMER	.	80	.	.	1	58A
VELPAR L	1 LB	WATER		G	FALL	17	.	.	.	.	28
VELPAR L	1 LB	WATER		G	FALL	9	.	.	.	.	28
VELPAR L	1 LB	WATER		G	FALL	33	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	FALL	80	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	FALL	45	.	.	.	.	28
VELPAR L	2 LB	WATER		G	FALL	83	.	.	.	.	28
VELPAR L	2 LB	WATER		G	FALL	100	.	.	.	.	28
VELPAR L	4 LB	WATER		G	FALL	100	.	.	.	.	28
(VELPAR +	2 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	20	.	4	43E
(VELPAR +	1 LB					.	.	.	.	.	
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	.	.	20	.	4	43G
WEEDONE 170	3 QT	WATER	3 QT DIESEL	G15	L SUMMER	.	100	.	.	.	23

PINEGRASS (CALAMAGROSTIS RUBESCENS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
(2,4-D +	4.2 LB					.	.	.	.	.	
DALAPON)	8 LBS	WATER	1PT SURFACT	S100	E FOLIAR	80	.	.	.	OP	61
ATRAZINE	10 LB	WATER		S10	E FOLIAR	.	30	.	.	.	52L
ATRAZINE	4 LB	WATER		G20	E FOLIAR	44	.	.	.	.	12
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	60	.	.	.	52K
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52M
ATRAZINE	4 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52N
ATRAZINE	5 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52P
ATRAZINE	4 LB	WATER		G20	L FOLIAR	0	.	.	.	.	12
ATRAZINE	5 LB	WATER		S10	L FOLIAR	.	20	.	.	.	52Q
ATRAZINE	4 LB	WATER		G20	L SUMMER	0	.	.	.	.	12
ATRAZINE	4 LB	WATER		S10	L SUMMER	.	10	.	.	.	52O
(DALAPON +	8.5 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G20	E FOLIAR	100	.	.	.	.	12
(DALAPON +	8.5 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G20	L FOLIAR	0	.	.	.	.	12
(DALAPON +	8.5 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G20	L SUMMER	0	.	.	.	.	12
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	40	.	.	.	52L
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52M
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52N
DALAPON	7.4 LB	WATER		S10	E FOLIAR	.	20	.	.	.	52P
DALAPON	8.5 LB	WATER		G20	E FOLIAR	97	.	.	.	.	12
DALAPON	7.4 LB	WATER		S10	L FOLIAR	.	40	.	.	.	52Q
DALAPON	8.5 LB	WATER		G20	L FOLIAR	36	.	.	.	.	12

PINEGRASS (CALAMAGROSTIS RUBESCENS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
DALAPON	7.4 LB	WATER		S10	L SUMMER	.	50	.	.	.	52O
DALAPON	8.5 LB	WATER		G20	L SUMMER	0	.	.	.	.	12
GARLON 4	2 LB	WATER	3%NT,MORACT	10	L FOLIAR	0	.	.	.	2	44L
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	0	.	.	.	5	44B
ROUNDUP	1 LB	WATER		G20	E FOLIAR	93	.	.	.	.	12
ROUNDUP	1 LB	WATER		S7	E FOLIAR	80	.	.	.	0P	53B
ROUNDUP	1 LB	WATER		S10	E FOLIAR	100	.	.	.	0P	53C
ROUNDUP	2 LB	WATER	.5% SURFACT	S25	E FOLIAR	80	.	.	.	0P	54A
ROUNDUP	2 LB	WATER		GDP	E FOLIAR	100	.	.	.	0P	53D
ROUNDUP	2 LB	WATER	.5% DYE	S3	E FOLIAR	80	.	.	.	0P	54B
ROUNDUP	2 LB	WATER	.5%FIRECHEM	G10	E FOLIAR	100	.	.	.	.	47
ROUNDUP	2 LB	WATER		S10	E FOLIAR	.	40	.	.	.	52N
ROUNDUP	3 LB	WATER		G20	E FOLIAR	99	.	.	.	.	12
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	90	.	.	.	52L
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	10	.	.	.	52M
ROUNDUP	3 LB	WATER		S10	E FOLIAR	.	0	.	.	.	52P
ROUNDUP	4 LB	WATER		S	E FOLIAR	60	.	.	.	0P	59A
ROUNDUP	4 LB	WATER		S	E FOLIAR	80	.	.	.	0P	59C
ROUNDUP	4 LB	WATER		S	E FOLIAR	80	.	.	.	0P	59D
ROUNDUP	4 LB	WATER		S	E FOLIAR	80	.	.	.	0P	59E
ROUNDUP	4 LB	WATER		S	E FOLIAR	60	.	.	.	0P	59F
ROUNDUP	0.3 LB	WATER		S1.5	L FOLIAR	80	.	.	.	0P	45
ROUNDUP	1 LB	WATER		G20	L FOLIAR	0	.	.	.	.	12
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	100	.	.	.	2	58B
ROUNDUP	2 LB	WATER	1% R-11, NT	10.7	L FOLIAR	60	.	.	.	2	44F
ROUNDUP	2 LB	WATER	<1% NT	10.6	L FOLIAR	60	.	.	.	1	44G
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	80	.	.	.	0	44H
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	80	.	.	.	0	44I
ROUNDUP	2 LB	WATER	1%NT,MORACT	10.5	L FOLIAR	60	.	.	.	2	44J
ROUNDUP	2 LB	WATER	3%	S	L FOLIAR	100	.	.	.	.	48
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	.	60	.	.	.	40A
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	100	.	.	.	.	40B
ROUNDUP	2 LB	WATER	1% SURFACT	S10	L FOLIAR	100	.	.	.	.	49
ROUNDUP	3 LB	WATER		S10	L FOLIAR	.	40	.	.	.	52P
ROUNDUP	3 LB	WATER		G20	L FOLIAR	0	.	.	.	.	12
ROUNDUP	4 LB	WATER		S	L FOLIAR	80	.	.	.	0P	59B
ROUNDUP	0.25 LB	WATER		S6.6	L SUMMER	100	.	.	.	.	60
ROUNDUP	1 LB	WATER		G20	L SUMMER	0	.	.	.	.	12
ROUNDUP	2 LB	WATER		S10	L SUMMER	.	50	.	.	.	52O
ROUNDUP	3 LB	WATER		G20	L SUMMER	65	.	.	.	.	12
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	60	.	.	.	52S
ROUNDUP	3 LB	WATER		S10	L FOLIAR	.	40	.	.	.	52Q
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	60	.	.	.	52S
(ROUNDUP +	2 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G20	E FOLIAR	90	.	.	.	.	12
(ROUNDUP +	2 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G20	L FOLIAR	0	.	.	.	.	12
(ROUNDUP +	2 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G20	L SUMMER	0	.	.	.	.	12
(ROUNDUP +	2 LB					.	.	.	.	.	
VELPAR)	2 LB	WATER		G20	E FOLIAR	85	.	.	.	.	12
(ROUNDUP +	2 LB					.	.	.	.	.	
VELPAR)	2 LB	WATER		G20	L FOLIAR	0	.	.	.	.	12
(ROUNDUP +	2 LB					.	.	.	.	.	
VELPAR)	2 LB	WATER		G20	L SUMMER	0	.	.	.	.	12

PINEGRASS (CALAMAGROSTIS RUBESCENS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
VELPAR L	1 LB	WATER		G	DORMANT	68	.	.	.	.	28
VELPAR L	1 LB	WATER		G	DORMANT	69	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	DORMANT	91	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	DORMANT	79	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	84	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	97	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	95	.	.	.	.	28
VELPAR L	4 LB	WATER		G	DORMANT	100	.	.	.	.	28
VELPAR L	2 LB	WATER		G20	E FOLIAR	66	.	.	.	.	12
VELPAR L	2 LB	WATER		S10	E FOLIAR	.	80	.	.	.	52K
VELPAR G	2 LB	GRANULE		S	E FOLIAR	.	80	.	.	.	52K
VELPAR G	2 LB	GRANULE		S	E FOLIAR	.	20	.	.	.	52M
VELPAR L	2 LB	WATER		S10	E FOLIAR	.	70	.	.	.	52N
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	100	.	.	.	52L
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	40	.	.	.	52M
VELPAR L	3 LB	WATER		S10	E FOLIAR	.	40	.	.	.	52P
VELPAR L	2 LB	WATER		G20	L FOLIAR	0	.	.	.	.	12
VELPAR L	3 LB	WATER		S10	L FOLIAR	.	70	.	.	.	52Q
VELPAR L	4 LB	WATER		S100	L FOLIAR	.	100	.	.	0	41
VELPAR G	1.4 LB	GRANULE		G	L SUMMER	.	90	.	.	.	52S
VELPAR L	2 LB	WATER		G20	L SUMMER	0	.	.	.	.	12
VELPAR L	2 LB	WATER		S10	L SUMMER	.	70	.	.	.	52O
VELPAR L	1 LB	WATER		G	FALL	10	.	.	.	.	28
VELPAR L	1 LB	WATER		G	FALL	23	.	.	.	.	28
VELPAR L	1 LB	WATER		G	FALL	58	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	FALL	100	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	FALL	54	.	.	.	.	28
VELPAR G	1 LB	GRANULE		S	FALL	.	20	.	.	.	52B
VELPAR L	2 LB	WATER		G	FALL	92	.	.	.	.	28
VELPAR L	2 LB	WATER		G	FALL	100	.	.	.	.	28
VELPAR L	2 LB	WATER		G	FALL	95	.	.	.	.	28
VELPAR G	2 LB	GRANULE		S	FALL	.	40	.	.	.	52B
VELPAR G	3 LB	GRANULE		S	FALL	.	70	.	.	.	52B
VELPAR L	4 LB	WATER		G	FALL	100	.	.	.	.	28
VELPAR G	4 LB	GRANULE		S	FALL	.	80	.	.	.	52B
VELPAR G	5 LB	GRANULE		S	FALL	.	80	.	.	.	52B

FORBS

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
2,4-D ESTER	1.5 LB	WATER		G	DORMANT	3	0	.	.	.	11
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	G15	L FOLIAR	.	82	.	.	2	57D
2,4-D ESTER	2 LB	WATER		G15	L FOLIAR	.	85	.	.	1	57D
2,4-D ESTER	3 LB	WATER		G15	L FOLIAR	.	86	.	.	1	57D
ATRAZINE	3 LB	WATER		G100	DORMANT	14	2	.	.	3	10
ATRAZINE	4 LB	WATER		G100	DORMANT	34	2	.	.	3	10
ATRAZINE	4 LB	WATER		G	DORMANT	7	0	.	.	0	11
ATRAZINE	1 LB	WATER		G17	E FOLIAR	5	.	.	.	.	29
ATRAZINE	2 LB	WATER		G17	E FOLIAR	77	.	.	.	.	29
ATRAZINE	3 LB	WATER		G17	E FOLIAR	94	.	.	.	.	29
ATRAZINE	4 LB	WATER		G20	E FOLIAR	20	0	.	.	.	2
ATRAZINE	4 LB	WATER		G17	E FOLIAR	95	.	.	.	.	29
ATRAZINE	4 LB	WATER		G200	E FOLIAR	37	.	.	.	0	5

FORBS

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
ATRAZINE	4 LB	WATER		G	E FOLIAR	33	.	.	.	0	5
(ATRAZINE +	3 LB					.	.	.	.	.	
2,4-D)	0.5 LB	WATER		G100	DORMANT	27	13	.	.	1	10
(ATRAZINE +	4 LB					.	.	.	.	.	
2,4-D)	1.5 LB	WATER		G	DORMANT	69	0	.	.	.	11
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G	E FOLIAR	29	.	.	.	.	3
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G	E FOLIAR	86	.	.	.	.	3
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G	E FOLIAR	20	.	.	.	.	3
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G	E FOLIAR	79	.	.	.	.	3
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G200	E FOLIAR	70	.	.	.	0	5
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER		G	E FOLIAR	30	.	.	.	0	5
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER	.5% SURFACT	S	E FOLIAR	86	23	.	.	0	5
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER	.5% SURFACT	S	E FOLIAR	29	6	.	.	0	5
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER	.5% SURFACT	S	E FOLIAR	79	56	.	.	0	5
(DALAPON +	8 LB					.	.	.	.	.	
ATRAZINE)	4 LB	WATER	.5% SURFACT	S	E FOLIAR	20	10	.	.	0	5
CASORON W50	2 LB	WATER		G100	DORMANT	6	4	.	.	1	10
CASORON W50	4 LB	WATER		G100	DORMANT	3	4	.	.	2	10
CASORON W50	6 LB	WATER		G100	DORMANT	27	9	.	.	3	10
CASORON G-4	2 LB	GRANULE		G	DORMANT	12	15	.	.	2	10
CASORON G-4	4 LB	GRANULE		G	DORMANT	28	22	.	.	2	10
CASORON G-4	6 LB	GRANULE		G	DORMANT	40	15	.	.	3	10
DALAPON	13.6 LB	WATER		G100	DORMANT	8	7	.	.	3	10
DALAPON	6.8 LB	WATER		G100	DORMANT	11	28	.	.	1	10
DALAPON	12 LB	WATER		G	E FOLIAR	0	.	.	.	.	26
DALAPON	4 LB	WATER		G	E FOLIAR	0	.	.	.	.	26
DALAPON	4 LB	WATER		G	E FOLIAR	1	.	.	.	.	3
DALAPON	4 LB	WATER		G	E FOLIAR	10	.	.	.	.	3
DALAPON	4 LB	WATER		G	E FOLIAR	4	.	.	.	.	3
DALAPON	4 LB	WATER		G	E FOLIAR	9	.	.	.	.	3
DALAPON	4 LB	WATER	.5% SURFACT	S	E FOLIAR	1	0	.	.	0	5
DALAPON	4 LB	WATER	.5% SURFACT	S	E FOLIAR	10	0	.	.	0	5
DALAPON	4 LB	WATER	.5% SURFACT	S	E FOLIAR	9	1	.	.	0	5
DALAPON	4 LB	WATER	.5% SURFACT	S	E FOLIAR	4	0	.	.	0	5
DALAPON	8 LB	WATER		G	E FOLIAR	0	.	.	.	.	26
DALAPON	8 LB	WATER		G	E FOLIAR	4	.	.	.	.	3
DALAPON	8 LB	WATER		G	E FOLIAR	11	.	.	.	.	3
DALAPON	8 LB	WATER		G	E FOLIAR	15	.	.	.	.	3
DALAPON	8 LB	WATER	.5% SURFACT	S	E FOLIAR	11	0	.	.	0	5
DALAPON	8 LB	WATER	.5% SURFACT	S	E FOLIAR	15	0	.	.	0	5
DALAPON	8 LB	WATER	.5% SURFACT	S	E FOLIAR	4	0	.	.	0	5
DALAPON	8 LB	WATER		G200	E FOLIAR	10	.	.	.	0	5
DALAPON	12 LB	WATER		G	L FOLIAR	0	.	.	.	.	26

FORBS

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	%TOP KILL YR1	%TOP KILL YR2	%TOP KILL YR3	PLANT KILL%	TREE INJURY	REF
DALAPON	4 LB	WATER		G	L FOLIAR	0	.	.	.	.	26
DALAPON	8 LB	WATER		G	L FOLIAR	0	.	.	.	.	26
GARLON 4	2 LB	WATER	3 QT DIESEL	G15	L FOLIAR	.	100	.	.	2	57D
ROUNDUP	2 LB	WATER		G48	DORMANT	0	.	.	.	.	24
ROUNDUP	1 LB	WATER		S7	E FOLIAR	20	.	.	.	0P	53B
ROUNDUP	1 LB	WATER		S10	E FOLIAR	100	.	.	.	0P	53C
ROUNDUP	2 LB	WATER		G48	L FOLIAR	84	.	.	.	.	24
ROUNDUP	2 LB	WATER		G15	L FOLIAR	.	76	.	.	1	57D
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	.	100	.	.	.	40A
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	100	.	.	.	.	40B
ROUNDUP	2 LB	WATER	1% SURFACT	S10	L FOLIAR	100	.	.	.	.	49
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	10	.	.	.	52I
ROUNDUP	3 LB	WATER		G10	L SUMMER	.	20	.	.	.	52I
TORDON 101	1 GAL	WATER		G15	L FOLIAR	.	91	.	.	5	57D
VELPAR L	1 LB	WATER		G	DORMANT	0	.	.	.	.	28
VELPAR L	1 LB	WATER		G	DORMANT	12	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	DORMANT	0	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	DORMANT	37	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	43	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	0	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	25	.	.	.	.	28
VELPAR L	2 LB	WATER		G	DORMANT	82	.	.	.	.	28
VELPAR L	4 LB	WATER		G	DORMANT	100	.	.	.	.	28
VELPAR L	1 LB	WATER		G17	E FOLIAR	18	.	.	.	.	29
VELPAR L	2 LB	WATER		G200	E FOLIAR	85	.	.	.	.	6
VELPAR L	2 LB	WATER		G17	E FOLIAR	82	.	.	.	.	29
VELPAR L	3 LB	WATER		G17	E FOLIAR	91	.	.	.	.	29
VELPAR L	4 LB	WATER		G17	E FOLIAR	98	.	.	.	.	29
VELPAR L	4 LB	WATER		G15	L FOLIAR	.	70	.	.	1	57D
VELPAR L	4 LB	WATER		G15	L FOLIAR	.	73	.	.	1	57D
VELPAR L	4 LB	WATER		G15	L FOLIAR	.	83	.	.	1	57D
VELPAR L	1 LB	WATER		G	FALL	0	.	.	.	.	28
VELPAR L	1 LB	WATER		G	FALL	37	.	.	.	.	28
VELPAR L	1 LB	WATER		G	FALL	36	.	.	.	.	28
VELPAR L	1.5 LB	WATER		G	FALL	0	.	.	.	.	28
VELPAR L	2 LB	WATER		G	FALL	43	.	.	.	.	28
VELPAR L	2 LB	WATER		G	FALL	0	.	.	.	.	28
VELPAR L	2 LB	WATER		G	FALL	64	.	.	.	.	28
VELPAR L	4 LB	WATER		G	FALL	100	.	.	.	.	28
VELPAR L	4 LB	WATER		G	FALL	69	.	.	.	.	28

THISTLE (CIRSIUM SPP.)

2,4-D ESTER	2 LB	WATER		S10	L SUMMER	.	90	.	.	.	52F
2,4-D ESTER	2 LB	WATER		G10	L SUMMER	.	90	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	S10	L SUMMER	.	70	.	.	.	52F
2,4-D ESTER	2 LB	WATER	2 QT DIESEL	G10	L SUMMER	.	90	.	.	.	52F
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G15	L SUMMER	100	.	.	.	.	23
ROUNDUP	3 LB	WATER		10	L SUMMER	.	70	.	.	.	52G
ROUNDUP	3 LB	WATER		S10	L SUMMER	.	90	.	.	.	52G
WEEDONE 170	6 QT	WATER	3 QT DIESEL	G15	L SUMMER	100	.	.	.	.	23

WHITE PINE (PINUS MONTICOLA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	0	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	3	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G15	E FOLIAR	1	23
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	G15	L SUMMER	1	23
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	6	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	6	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	6	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	6	32
GARLON 3A	3 LB	WATER		10	L SUMMER	0	20
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	3	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	6	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L FOLIAR	1	17
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	0	19
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	0	19
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	0	20
GARLON 4	2 LB	WATER	3 QT DIESEL	G15	L SUMMER	1	23
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	3	20
GARLON 4	5 LB	WATER	3 QT DIESEL	10	L SUMMER	3	20
(GARLON 4 +	1 LB						
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	3	13
ROUNDUP	0.75 QT	WATER		7.5	L FOLIAR	0	16
ROUNDUP	1 LB	WATER		10	L FOLIAR	0	16
ROUNDUP	1.5 QT	WATER	1% R-11	5	L FOLIAR	0	17
ROUNDUP	1.5 QT	WATER		7.5	L FOLIAR	0	17
ROUNDUP	1.5 QT	WATER		10	L FOLIAR	0	17
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	0	44D
ROUNDUP	2 LB	WATER		7.5	L FOLIAR	0	17
ROUNDUP	2 LB	WATER		10	L FOLIAR	0	16
ROUNDUP	2 LB	WATER		10	L FOLIAR	0	17
ROUNDUP	3 LB	WATER		10	L FOLIAR	0	16
ROUNDUP	1 LB	WATER		G15	L SUMMER	0	23
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	0	50A
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	2	43B
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62A
ROUNDUP	2 LB	WATER		10	L SUMMER	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	0	13
ROUNDUP	2 LB	WATER		G15	L SUMMER	0	23
ROUNDUP	2 LB	WATER		10	L SUMMER	0	50D
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	0	42
ROUNDUP	2 LB	WATER		S10	FALL	5	52Z
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	6	32
TORDON 101	1 GAL	WATER		10	L SUMMER	0	13
(TORDON 101 +	1.5 GAL						
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	6	13
(TORDON 101 +	1 GAL	WATER					
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	2	13
(TORDON 101 +	1.5 GAL	WATER					
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	4	13
VELPAR L	2 LB	WATER	.1% NT	10	DORMANT	0	43H
VELPAR L	1 LB	WATER		S10	E FOLIAR	5	52Z
VELPAR L	2 LB	WATER		S10	E FOLIAR	6	52Z

WHITE PINE (PINUS MONTICOLA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
VELPAR L	2 LB	WATER		S10	L FOLIAR	6	52Z
VELPAR G	2 LB	GRANULE		S	E FOLIAR	6	52Z
VELPAR L	3 LB	WATER		S10	E FOLIAR	6	52Z
VELPAR L	1 LB	WATER		S10	L FOLIAR	5	52Z
VELPAR G	2 LB	GRANULE		S	L FOLIAR	6	52Z
VELPAR L	3 LB	WATER		S10	L FOLIAR	5	52Z
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	0	19
VELPAR G	2 LB	GRANULE		S	FALL	0	52B
VELPAR L	2 LB	WATER		S10	FALL	6	52Z
VELPAR G	2 LB	GRANULE		S	FALL	5	52Z
VELPAR G	4 LB	GRANULE		S	FALL	0	52B

WESTERN LARCH (WESTERN LARCH)

2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	1	52R
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	1	13
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	1	52R
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	6	13
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	4	44B
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	0	19
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	5	19
ROUNDUP	2 LB	WATER		10	E FOLIAR	6	13
ROUNDUP	4 LB	WATER		S	E FOLIAR	0P	59D
ROUNDUP	4 LB	WATER		S	E FOLIAR	0P	59F
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	4	44D
ROUNDUP	2 LB	WATER		10	L FOLIAR	2	52R
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	4	44A
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	4	44C
ROUNDUP	4 LB	WATER		S	L FOLIAR	0P	59B
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	4	50A
ROUNDUP	2 LB	WATER		10	L SUMMER	6	50C
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	0	42
ROUNDUP	2 LB	WATER		S10	FALL	5	52Z
(ROUNDUP +	2 LB						
2,4-D,2,4-DP)	2 LB	WATER	5%R-11,TV	10	L SUMMER	6	43A
TORDON 101	1 GAL	WATER		10	E FOLIAR	3	13
VELPAR L	1 LB	WATER		S10	E FOLIAR	6	52Z
VELPAR L	2 LB	WATER		S10	E FOLIAR	6	52Z
VELPAR G	2 LB	GRANULE		S1	E FOLIAR	6	52Z
VELPAR L	3 LB	WATER		S10	E FOLIAR	6	52Z
VELPAR L	1 LB	WATER		S10	L FOLIAR	6	52Z
VELPAR L	2 LB	WATER		S10	L FOLIAR	6	52Z
VELPAR G	2 LB	GRANULE		S	L FOLIAR	6	52Z
VELPAR L	3 LB	WATER		S10	L FOLIAR	6	52Z
VELPAR L	2 LB	WATER		S10	FALL	6	52Z
VELPAR G	2 LB	GRANULE		S	FALL	6	52Z
(VELPAR +	2 LB						
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	4	43E
(VELPAR +	1 LB						
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	4	43G

DOUGLAS FIR (PSEUDOTSUGA MENZIESII)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	1	39
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	0	13
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	G10	L SUMMER	1	57E
2,4-D ESTER	2 LB	WATER		10	E FOLIAR	1	39
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	5	13
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	0	52R
2,4-D ESTER	4 LB	WATER	2% MORACT	15	L FOLIAR	2	51
2,4-D ESTER	2 LB	WATER		10	L SUMMER	1	39
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	3	13
(2,4-D +	2 LB						
2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	4	43F
(2,4-D +	4.2 LB						
DALAPON)	8 LBS	WATER	1PT SURFACT	S100	E FOLIAR	0P	61
ASULOX	2 LB	WATER		GDP	E FOLIAR	3	36
ASULOX	2 LB	WATER		GDP	L FOLIAR	1	36
ASULOX	3 LB	WATER	.2% CHIPCO	10	L FOLIAR	1	37
ASULOX	3.3 LB	WATER	.2% CHIPCO	10	L FOLIAR	1	37
ASULOX	3.3 LB	WATER		10	L FOLIAR	3	37
ASULOX	2 LB	WATER		GDP	L SUMMER	1	36
ATRAZINE	3 LB	WATER		G100	DORMANT	3	10
ATRAZINE	4 LB	WATER		G100	DORMANT	3	10
(ATRAZINE +	3 LB						
2,4-D)	0.5 LB	WATER		G100	DORMANT	1	10
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	3	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	6	32
CASORON W50	2 LB	WATER		G100	DORMANT	1	10
CASORON W50	4 LB	WATER		G100	DORMANT	2	10
CASORON W50	6 LB	WATER		G100	DORMANT	3	10
CASORON G 4	2 LB	GRANULE		G	DORMANT	2	10
CASORON G 4	4 LB	GRANULE		G	DORMANT	2	10
CASORON G 4	6 LB	GRANULE		G	DORMANT	2	10
DALAPON	13.6 LB	WATER		G100	DORMANT	3	10
DALAPON	6.8 LB	WATER		G100	DORMANT	1	10
DICAMBA	2 LB	WATER		GDP	L FOLIAR	3	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	5	32
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	0	52R
GARLON 3A	3 LB	WATER		10	L SUMMER	0	20
GARLON 4	1 LB	OIL		10	DORMANT	0	39
GARLON 4	1 LB	OIL		10	DORMANT	1	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	1	39
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	1	13
GARLON 4	1.5 LB	WATER		10	E FOLIAR	1	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	6	13
GARLON 4	2 LB	WATER	1%NT,MORACT	10.6	L FOLIAR	2	44K
GARLON 4	2 LB	WATER	3%NT,MORACT	10	L FOLIAR	2	44L
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	4	44B
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	0	19
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	1	13
GARLON 4	1.5 LB	WATER		10	L SUMMER	1	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	0	19
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	1	20

DOUGLAS FIR (PSEUDOTSUGA MENZIESII)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
GARLON 4	2 LB	WATER	3 QT DIESEL	G10	L SUMMER	4	57E
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	0	20
GARLON 4	5 LB	WATER	3 QT DIESEL	10	L SUMMER	2	20
(GARLON 4 + 2,4-D ESTER)	1 LB 2 LB	WATER	3 QT DIESEL	G10	L SUMMER	3	57E
(GARLON 4 + 2,4-D ESTER)	1 LB 1 LB	WATER	3 QT DIESEL	G10	L SUMMER	2	57E
(GARLON 4 + 2,4-D ESTER)	1.5 LB 1.5 LB	WATER	3 QT DIESEL	G10	L SUMMER	3	57E
(GARLON 4 + 2,4-D ESTER)	2 LB 1 LB	WATER	3 QT DIESEL	G10	L SUMMER	3	57E
(GARLON 4 + 2,4-D ESTER)	1 LB 2 LB	WATER	3 QT DIESEL	10	E FOLIAR	1	13
(GARLON 4 + 2,4-D ESTER)	2 LB 2 LB	WATER	3 QT DIESEL	10	E FOLIAR	5	13
ROUNDUP	2 LB	WATER	.5% SURFACT	S25	E FOLIAR	0P	54A
ROUNDUP	2 LB	WATER	.5% DYE	S3	E FOLIAR	0P	54B
ROUNDUP	2 LB	WATER		S10	E FOLIAR	5	52Z
ROUNDUP	2 LB	WATER		10	E FOLIAR	5	13
ROUNDUP	3 LB	WATER		S10	E FOLIAR	5	52Z
ROUNDUP	4 LB	WATER		S	E FOLIAR	0P	59D
ROUNDUP	4 LB	WATER		S	E FOLIAR	0P	59E
ROUNDUP	4 LB	WATER		S	E FOLIAR	0P	59F
ROUNDUP	0.75 QT	WATER		7.5	L FOLIAR	1	16
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	4	58B
ROUNDUP	1 LB	WATER		10	L FOLIAR	0	16
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	2	44D
ROUNDUP	2 LB	WATER	3% NT,DYE	10.6	L FOLIAR	2	44E
ROUNDUP	2 LB	WATER	1% R-11,NT	10.7	L FOLIAR	2	44F
ROUNDUP	2 LB	WATER	<1% NT	10.6	L FOLIAR	0	44G
ROUNDUP	2 LB	WATER	1%NT,MORACT	10.5	L FOLIAR	2	44J
ROUNDUP	2 LB	WATER		S10	L FOLIAR	3	52Z
ROUNDUP	2 LB	WATER		10	L FOLIAR	1	16
ROUNDUP	2 LB	WATER		10	L FOLIAR	0	52R
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	4	44C
ROUNDUP	3 LB	WATER		S10	L FOLIAR	4	52Z
ROUNDUP	3 LB	WATER		10	L FOLIAR	1	16
ROUNDUP	4 LB	WATER		S	L FOLIAR	0P	59B
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	0	50A
ROUNDUP	2 LB	WATER	.6% R-11	G20	L SUMMER	0	43B
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62A
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62B
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62C
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62D
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62E
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62F
ROUNDUP	2 LB	WATER		S10	L SUMMER	0	52Z
ROUNDUP	2 LB	WATER		10	L SUMMER	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	0	13
ROUNDUP	2 LB	WATER		10	L SUMMER	0	50B
ROUNDUP	2 LB	WATER		10	L SUMMER	0	50C
ROUNDUP	2 LB	WATER		10	L SUMMER	0	50D
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	0	42
ROUNDUP	3 LB	WATER		S10	L SUMMER	1	52Z

DOUGLAS FIR (PSEUDOTSUGA MENZIESII)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
ROUNDUP	2 LB	WATER		S10	FALL	0	52Z
(ROUNDUP +	2 LB						
2,4-D,2,4-DP)	2 LB	WATER	5% R-11	10	L SUMMER	4	43A
(ROUNDUP +	2 LB						
GARLON 4)	1 LB	WATER		10	L SUMMER	0	13
TORDON 101	1 GAL	WATER		10	E FOLIAR	3	13
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	5	32
TORDON 101	1 GAL	WATER		10	L SUMMER	1	13
(TORDON 101 +	1 GAL						
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	5	13
(TORDON 101 +	1.5 GAL						
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	6	13
(TORDON 101 +	1 GAL	WATER					
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	3	13
(TORDON 101 +	1.5 GAL	WATER					
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	3	13
VELPAR L	2 LB	WATER	.1% NT	10	DORMANT	0	43H
VELPAR L	1 LB	WATER		S10	E FOLIAR	2	52Z
VELPAR L	2 LB	WATER		S10	E FOLIAR	3	52Z
VELPAR G	2 LB	GRANULE		S	E FOLIAR	3	52Z
VELPAR L	3 LB	WATER		S10	E FOLIAR	4	52Z
VELPAR L	1 LB	WATER		S10	L FOLIAR	0	52Z
VELPAR L	2 LB	WATER		S10	L FOLIAR	0	52Z
VELPAR G	2 LB	GRANULE		S	L FOLIAR	1	52Z
VELPAR L	3 LB	WATER		S10	L FOLIAR	1	52Z
VELPAR L	2 LB	WATER	2.2 %MORACT	10	L SUMMER	0	58A
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	0	19
VELPAR G	2 LB	GRANULE		S	FALL	0	52B
VELPAR L	2 LB	WATER		S10	FALL	1	52Z
VELPAR G	2 LB	GRANULE		S	FALL	0	52Z
VELPAR G	4 LB	GRANULE		S	FALL	0	52B
(VELPAR +	2 LB						
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	4	43E
(VELPAR +	1 LB						
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	4	43G

GRAND FIR (ABIES GRANDIS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	1	39
2,4-D ESTER	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	0	13
2,4-D ESTER	2 LB	WATER		10	E FOLIAR	1	39
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	0	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	E FOLIAR	5	13
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	0	52R
2,4-D ESTER	2 LB	WATER		10	L SUMMER	1	39
2,4-D ESTER	3 LB	WATER	3 QT DIESEL	10	L SUMMER	3	13
2,4-D ESTER	4 LB	WATER	3 QT DIESEL	10	L SUMMER	3	13
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	6	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	6	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	6	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	6	32
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	0	52R

GRAND FIR (ABIES GRANDIS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
GARLON 3A	3 LB	WATER		10	L SUMMER	0	20
GARLON 4	1 LB	OIL		10	DORMANT	0	39
GARLON 4	1 LB	OIL		10	DORMANT	0	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	1	39
GARLON 4	1 LB	WATER	3 QT DIESEL	10	E FOLIAR	4	13
GARLON 4	1.5 LB	WATER		10	E FOLIAR	1	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	5	13
GARLON 4	3 LB	WATER	3 QT DIESEL	10	E FOLIAR	6	13
GARLON 4	2 LB	WATER	1%NT,MORACT	10.6	L FOLIAR	2	44K
GARLON 4	2 LB	WATER	3%NT,MORACT	10	L FOLIAR	4	44L
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	4	44B
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	0	19
GARLON 4	1 LB	WATER	3 QT DIESEL	10	L SUMMER	3	13
GARLON 4	1.5 LB	WATER		10	L SUMMER	0	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	5	13
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	0	19
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	3	20
GARLON 4	3 LB	WATER	3 QT DIESEL	10	L SUMMER	3	20
GARLON 4	5 LB	WATER	3 QT DIESEL	10	L SUMMER	3	20
(GARLON 4 +	1 LB						
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	1	13
(GARLON 4 +	2 LB						
2,4-D ESTER)	2 LB	WATER	3 QT DIESEL	10	E FOLIAR	5	13
(GARLON 4 +	3 LB						
2,4-D ESTER)	2 LB	WATER	3 QT MORACT	15	L FOLIAR	6	57B
ROUNDUP	2 LB	WATER		10	E FOLIAR	3	13
ROUNDUP	0.75 QT	WATER		7.5	L FOLIAR	0	16
ROUNDUP	1 LB	WATER		10	L FOLIAR	1	16
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	2	44D
ROUNDUP	2 LB	WATER	3% NT,DYE	10.6	L FOLIAR	2	44E
ROUNDUP	2 LB	WATER	1% R-11,NT	10.7	L FOLIAR	2	44F
ROUNDUP	2 LB	WATER	<1% NT	10.6	L FOLIAR	2	44G
ROUNDUP	2 LB	WATER		10	L FOLIAR	0	16
ROUNDUP	2 LB	WATER		10	L FOLIAR	0	52R
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	4	44A
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	4	44C
ROUNDUP	3 LB	WATER		10	L FOLIAR	1	16
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	0	50A
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	2	43B
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62A
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62B
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62C
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62E
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62F
ROUNDUP	2 LB	WATER		10	L SUMMER	0	13
ROUNDUP	2 LB	WATER	1% R-11	10	L SUMMER	0	13
ROUNDUP	2 LB	WATER		10	L SUMMER	0	50B
ROUNDUP	2 LB	WATER		10	L SUMMER	0	50C
ROUNDUP	2 LB	WATER		10	L SUMMER	0	50D
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	0	42
(ROUNDUP +	2 LB						
GARLON 4)	1 LB	WATER		10	L SUMMER	0	13
TORDON 101	1 GAL	WATER		10	E FOLIAR	5	13
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	6	32

GRAND FIR (ABIES GRANDIS)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
TORDON 101	1 GAL	WATER	NALCO-TROL	15	L FOLIAR	6	15
TORDON 101	1 GAL	WATER		10	L SUMMER	1	13
(TORDON 101 +	1 GAL						
2,4-D ESTER)	2 LB	WATER		10	E FOLIAR	5	13
(TORDON 101 +	1.5 GAL						
2,4-D ESTER)	1 LB	WATER		10	E FOLIAR	6	13
(TORDON 101 +	1 GAL	WATER					
2,4-D ESTER)	2 LB	WATER		10	L SUMMER	5	13
(TORDON 101 +	1.5 GAL	WATER					
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	1	13
VELPAR L	2 LB	WATER	.1% NT	10	DORMANT	2	43H
VELPAR L	3 LB	WATER	DEFOAMER	10	L SUMMER	0	19
VELPAR G	2 LB	GRANULE		S	FALL	0	52B
VELPAR G	4 LB	GRANULE		S	FALL	0	52B
(VELPAR +	2 LB						
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	6	43E

WESTERN HEMLOCK (TSUGA HETEROHYLLA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	1	39
2,4-D ESTER	2 LB	WATER		10	E FOLIAR	1	39
2,4-D ESTER	2 LB	WATER		10	L SUMMER	1	39
GARLON 4	1 LB	OIL		10	DORMANT	0	39
GARLON 4	1 LB	OIL		10	DORMANT	0	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	1	39
GARLON 4	1.5 LB	WATER		10	E FOLIAR	1	39
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	6	44B
GARLON 4	1.5 LB	WATER		10	L SUMMER	0	39
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	4	44A
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	6	44C
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	0	50A
ROUNDUP	2 LB	WATER		10	L SUMMER	0	50C

WESTERN REDCEDAR (THUJA PLICATA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	1	39
2,4-D ESTER	2 LB	WATER		10	E FOLIAR	1	39
2,4-D ESTER	2 LB	WATER		10	L SUMMER	1	39
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	5	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	6	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	6	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	6	32
GARLON 4	1 LB	OIL		10	DORMANT	0	39
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	1	39
GARLON 4	1.5 LB	WATER		10	E FOLIAR	1	39
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	4	44B
GARLON 4	1.5 LB	WATER		10	L SUMMER	0	39
GARLON 4	2 LB	WATER	3 QT DIESEL	10	L SUMMER	0	13
ROUNDUP	2 LB	WATER		10	E FOLIAR	0	13
ROUNDUP	2 LB	WATER		10	L FOLIAR	2	52R

WESTERN REDCEDAR (THUJA PLICATA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	2	44A
ROUNDUP	3 LB	WATER	3% NT,R-11	10	L FOLIAR	4	44C
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62A
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62C
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62D
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62F
ROUNDUP	2 LB	WATER		10	L SUMMER	1	50B
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	6	32
TORDON 101	1 GAL	WATER	NALCO-TROL	15	L FOLIAR	6	15
(TORDON 101 +	1.5 GAL	WATER					
2,4-D ESTER)	1 LB	WATER		10	L SUMMER	3	13

LODGEPOLE PINE (PINUS CONTORTA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	6	39
2,4-D ESTER	2 LB	WATER		10	E FOLIAR	4	39
2,4-D ESTER	4.2 LB	WATER		10	L FOLIAR	0	52R
2,4-D ESTER	2 LB	WATER		10	L SUMMER	1	39
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	5	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	6	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	3	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	5	32
GARLON 3A	2.25 LB	WATER		15	L FOLIAR	0	52R
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	6	39
GARLON 4	1.5 LB	WATER		10	E FOLIAR	5	39
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	6	44B
GARLON 4	1.5 LB	WATER		10	L SUMMER	5	39
KRENITE	2 LB	WATER		15	L FOLIAR	1	52R
ROUNDUP	4 LB	WATER		S	E FOLIAR	0P	59C
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	2	58B
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	0	44H
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	0	44I
ROUNDUP	2 LB	WATER		10	L FOLIAR	0	52R
ROUNDUP	2 LB	WATER		10	L SUMMER	0	50C
ROUNDUP	2 LB	WATER		10	L SUMMER	0	50D
ROUNDUP	2 LB	WATER		S10	FALL	0	52Z
(ROUNDUP +	2 LB						
2,4-D,2,4-DP)	2 LB	WATER	5% R-11	10	L SUMMER	6	43A
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	5	32
VELPAR L	2 LB	WATER	.1% NT	10	DORMANT	2	43H
VELPAR L	1 LB	WATER		S10	E FOLIAR	1	52Z
VELPAR L	2 LB	WATER		S10	E FOLIAR	5	52Z
VELPAR G	2 LB	GRANULE		S	E FOLIAR	3	52Z
VELPAR L	3 LB	WATER		S10	E FOLIAR	5	52Z
VELPAR L	1 LB	WATER		S10	L FOLIAR	0	52Z
VELPAR L	2 LB	WATER		S10	L FOLIAR	1	52Z
VELPAR G	2 LB	GRANULE		S	L FOLIAR	2	52Z
VELPAR L	3 LB	WATER		S10	L FOLIAR	4	52Z
VELPAR L	4 LB	WATER		S100	L FOLIAR	0	41
VELPAR L	2 LB	WATER	2.2 %MORACT	10	L SUMMER	2	58A
VELPAR G	2 LB	GRANULE		S	FALL	0	52B
VELPAR L	2 LB	WATER		S10	FALL	1	52Z

LODGEPOLE PINE (PINUS CONTORTA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
VELPAR G	2 LB	GRANULE		S	FALL	0	52Z
VELPAR G	4 LB	GRANULE		S	FALL	0	52B
(VELPAR +	1 LB						
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	6	43G

ENGELMANN SPRUCE (PICEA ENGELMANII)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
(2,4-D +	2 LB						
2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	2	43F
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	6	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	6	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	6	32
DICAMBA	8 LB	WATER		GDP	L FOLIAR	6	32
ROUNDUP	2 LB	WATER	<1% NT	15	L SUMMER	0	50A
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	0	43C
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	0	43D
ROUNDUP	2 LB	WATER		S10	FALL	1	52Z
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	6	32
VELPAR L	1 LB	WATER		S10	E FOLIAR	2	52Z
VELPAR L	2 LB	WATER		S10	E FOLIAR	5	52Z
VELPAR G	2 LB	GRANULE		S	E FOLIAR	5	52Z
VELPAR L	3 LB	WATER		S10	E FOLIAR	5	52Z
VELPAR L	1 LB	WATER		S10	L FOLIAR	2	52Z
VELPAR L	2 LB	WATER		S10	L FOLIAR	2	52Z
VELPAR G	2 LB	GRANULE		S	L FOLIAR	3	52Z
VELPAR L	3 LB	WATER		S10	L FOLIAR	2	52Z
VELPAR L	2 LB	WATER		S10	FALL	1	52Z
VELPAR G	2 LB	GRANULE		S	FALL	2	52Z
(VELPAR +	2 LB						
2,4-D,2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	2	43E

SUBALPINE FIR (ABIES LASIOCARPA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
(2,4-D +	2 LB						
2,4-DP)	2 LB	WATER	8%MORACT,TV	10	L SUMMER	6	43F
ROUNDUP	2 LB	WATER		10	L FOLIAR	0	52R
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	2	43C
ROUNDUP	2 LB	WATER	.6% R-11	10	L SUMMER	2	43D

PONDEROSA PINE (PINUS PONDEROSA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
2,4-D ESTER	3 LB	OIL		10	DORMANT	6	39
2,4-D ESTER	2 LB	WATER		10	E FOLIAR	4	39
2,4-D ESTER	2 LB	WATER		10	L SUMMER	1	39
2,4-D ESTER	4 LB	WATER		G100	FALL	0	46A
(2,4-D +	4.2 LB						
DALAPON)	8 LBS	WATER	1PT SURFACT	S100	E FOLIAR	0P	61
ASULOX	2 LB	WATER		GDP	E FOLIAR	3	36
ASULOX	2 LB	WATER		GDP	L FOLIAR	1	36
ASULOX	2 LB	WATER		GDP	L SUMMER	1	36
BANVEL 720	1 GAL	WATER		GDP	L FOLIAR	6	32
BANVEL 720	4 GAL	WATER		GDP	L FOLIAR	6	32
DICAMBA	2 LB	WATER		GDP	L FOLIAR	6	32

PONDEROSA PINE (PINUS PONDEROSA)

HERBICIDE	RATE/ ACRE	CARRIER	ADJUVANT/ ACRE	GAL/ ACRE	SPRAY SEASON	TREE INJURY	REF
DICAMBA	8 LB	WATER		GDP	L FOLIAR	6	32
GARLON 3A	8 LB	WATER		G100	FALL	2	46A
(GARLON 3A +	2 LB						
TORDON 101)	4 LB	WATER		G100	FALL	2	46A
GARLON 4	2 LB	WATER	4 QT DIESEL	10	DORMANT	6	39
GARLON 4	1.5 LB	WATER		10	E FOLIAR	5	39
GARLON 4	4 LB	WATER	5%NT,MORACT	10	L FOLIAR	6	44B
GARLON 4	1.5 LB	WATER		10	L SUMMER	5	39
GARLON 4	4 LB	WATER		G100	FALL	2	46A
ROUNDUP	1 LB	WATER		S8	E FOLIAR	0P	53A
ROUNDUP	1 LB	WATER		S7	E FOLIAR	0P	53B
ROUNDUP	1 LB	WATER		S10	E FOLIAR	0P	53C
ROUNDUP	2 LB	WATER	.5% SURFACT	S25	E FOLIAR	0P	54A
ROUNDUP	2 LB	WATER		GDP	E FOLIAR	0P	53D
ROUNDUP	2 LB	WATER	.5% DYE	S3	E FOLIAR	0P	54B
ROUNDUP	2 LB	WATER		S10	E FOLIAR	4	52Z
ROUNDUP	3 LB	WATER		S10	E FOLIAR	6	52Z
ROUNDUP	4 LB	WATER		S	E FOLIAR	0P	59A
ROUNDUP	4 LB	WATER		S	E FOLIAR	0P	59D
ROUNDUP	4 LB	WATER		S	E FOLIAR	0P	59E
ROUNDUP	4 LB	WATER		S	E FOLIAR	0P	59F
ROUNDUP	1 LB	WATER	.9% R-11	12	L FOLIAR	2	58B
ROUNDUP	2 LB	WATER	3% NT,DYE	10.6	L FOLIAR	0	44E
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	0	44H
ROUNDUP	2 LB	WATER	<1% NT	10.5	L FOLIAR	0	44I
ROUNDUP	2.5 LB	WATER		S	L FOLIAR	0P	40B
ROUNDUP	2 LB	WATER		S10	L FOLIAR	1	52Z
ROUNDUP	3 LB	WATER		S10	L FOLIAR	3	52Z
ROUNDUP	4 LB	WATER		S	L FOLIAR	0P	59B
ROUNDUP	4 LB	WATER		G20	L FOLIAR	6	46B
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62A
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62C
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62E
ROUNDUP	2 LB	WATER		10.5	L SUMMER	0	62F
ROUNDUP	2 LB	WATER		S10	L SUMMER	0	52Z
ROUNDUP	3 LB	WATER	.8 OZ NT	10	L SUMMER	0	42
ROUNDUP	3 LB	WATER		S10	L SUMMER	1	52Z
ROUNDUP	2 LB	WATER		S10	FALL	1	52Z
TORDON 101	1 GAL	WATER		GDP	L FOLIAR	5	32
VELPAR L	1 LB	WATER		S10	E FOLIAR	1	52Z
VELPAR L	2 LB	WATER		S10	E FOLIAR	2	52Z
VELPAR G	2 LB	GRANULE		S	E FOLIAR	2	52Z
VELPAR L	3 LB	WATER		S10	E FOLIAR	1	52Z
VELPAR L	1 LB	WATER		S10	L FOLIAR	1	52Z
VELPAR L	2 LB	WATER		S10	L FOLIAR	1	52Z
VELPAR G	2 LB	GRANULE		S	L FOLIAR	1	52Z
VELPAR L	3 LB	WATER		S10	L FOLIAR	1	52Z
VELPAR L	2 LB	WATER	2.2 %MORACT	10	L SUMMER	2	58A
VELPAR G	2 LB	GRANULE		S	FALL	0	52B
VELPAR L	2 LB	WATER		S10	FALL	1	52Z
VELPAR G	2 LB	GRANULE		S	FALL	1	52Z
VELPAR G	4 LB	GRANULE		S	FALL	0	52B

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APPENDIX: HERBICIDE INQUIRY REPORTING FORM

Explanation of Form Items (not self-explanatory) and Plant List

Chemical - trade name of product

Rate - amount of active ingredient applied/acre, or per tree

Date applied - (month, day, year)

Method of application - aerial, backpack, squirt

Mode of application - spot, broadcast, cut surface

Gallons of total applied mix/acre

Adjuvants and percent of total mix - (consider surfactants and drift control substances)

Type of treatment - site preparation, conifer release, thinning, cull tree kill, cut surface of shrubs, other

Target species information -

(Some species are listed for you [see attached listing for codes and names]; add others as needed to complete the information.)

1. Check type of rating used.
2. For ratings of herbicide "kill" effects on target species please translate your observations and/or ratings to a 0-5 scale, with 0 = no effect; 5 = plants dead; and 1-4 = 20 percent increments of kill.
3. Sprouts: 0 = none
   1 = weak
   2 = moderate
   3 = vigorous.

Conifer damage information -

List species and rate chemical damage on a 0-6 scale where:

0 = No effect.

1 = 0 to 10 percent defoliation, no bud injury.

2 = 0 to 10 percent defoliation, slight tip curl, no bud injury.

3 = 11 to 40 percent defoliation, slight bud kill.

4 = 40+ percent defoliation, moderate bud kill.

5 = Slight to moderate top kill, 50+ percent defoliation.

6 = Trees killed.

Conifer response information -

If available, survival and growth comparisons. Include scalping or mechanical, if available.

Species Codes

Scientific name	Four-letter code	Common name
Acer glabrum	ACGL	Rocky Mountain maple
Alnus sinuata	ALSI	Sitka alder
Artemisia tridentata	ARTI	Sagebrush
Amelanchier alnifolia	AMAL	Serviceberry
Arctostaphylos uva-ursi	ARUV	Kinnikinnick
Berberis aquifolium	BEAQ	Tall Oregon-grape
Berberis repens	BERE	Oregon-grape
Bromus spp.	BROM	Brome
Calamagrostis canadensis	CACA	Bluejoint reedgrass
Calamagrostis rubescens	CARU	Pinegrass
Carex spp.	CARX	Sedge
Ceanothus sanguineus	CESA	Redstem ceanothus
Ceanothus velutinus	CEVE	Slickleaf ceanothus
Cirsium spp.	CIRS	Thistle
Clematis columbiana	CLCO	Clematis
Cornus nuttallii	CONU	Dogwood
Cornus stolonifera	COST	Red-osier dogwood
Crataegus douglasii	CRDO	Douglas hawthorn
Holodiscus discolor	HODI	Oceanspray
Juniperus spp.	JUNI	Juniper
Ledum gladulosum	LEGL	Labrador-tea
Linnaea borealis	LIBO	Twinflower
Lonicera caerulea	LOCA	Sweetberry honeysuckle
Lonicera ciliosa	LOCI	Trumpet honeysuckle
Lonicera involucrata	LOIN	Bearberry honeysuckle
Lonicera utahensis	LOUT	Utah honeysuckle
Menziesia ferruginea	MEFE	Menziesia
Oplopanax horridum	OPHO	Devil's club
Pachistima myrsinites	PAMY	Pachistima
Philadelphus lewisii	PHLE	Mock orange
Physocarpos malvaceus	PHMA	Ninebark
Populus tremuloides	POTR	Quaking aspen
Prunus spp.	PRUN	Cherry
Prunus emarginata	PREM	Bittercherry
Prunus virginiana	PRVI	Common chokecherry
Pteridium aquilinium	PTAQ	Bracken
Purshia tridentata	PUTR	Bitterbrush
Rhamus purshiana	RHPU	Buckthorn
Rhododendron albiflorum	RHAL	Cascades azalea
Rhus trilobata	RHTR	Skunkbush sumac
Ribes spp.	RIBE	Current
Rosa spp.	ROSA	Rose
Rubus spp.	RUBU	All rubus
Rubus leucodermis	RULE	Red raspberry
Rubus parviflorus	RUPA	Thimbleberry
Rubus ursinus	RUUR	Trailing blackberry
Salix spp. (shrub size)	SALX	Willow
Sambucus spp.	SAMB	Elderberry
Sambucus racemosa	SARA	European elderberry
Shepherdia canadensis	SHCA	Russet buffaloberry
Sorbus spp.	SORB	Ash
Spiraea betulifolia	SPBE	Shinyleaf spiraea
Spiraea pyramidata	SPPY	Pyramid spiraea
Symphoricarpos spp.	SYMP	Snowberry
Symphoricarpos albus	SYAL	Common snowberry

(con.)

Species Codes (con.)

Scientific name	Four-letter code	Common name
Symphoricarpos mollis	SYMO	Trailing snowberry
Symphoricarpos oreophilus	SYOR	Snowberry
Vaccinium spp.	VACC	Huckleberry
Vaccinium caespitosum	VACA	Dwarf huckleberry
Vaccinium globulare	VAGL	Globe huckleberry
Vaccinium membranaceum	VAME	Big huckleberry
Vaccinium scoparium	VASC	Grouse huckleberry
Miscellaneous plants	GRAS	Graminoids
	FORB	Other herbaceous
	MOSS	Mosses
	FERN	Ferns
	CONIFERS	
Pinus monticola	PIMO	Western white pine
Pinus contorta	PICO	Lodgepole pine
Pinus ponderosa	PIPO	Ponderosa pine
Pseudotsuga menziesii	PSME	Douglas-fir
Larix occidentalis	LAOC	Western larch
Abies grandis	ABGR	Grand fir
Abies lasiocarpa	ABLA	Subalpine fir
Picea engelmannii	PIEN	Engelmann spruce
Thuja plicata	THPL	Western redcedar
Tsuga heterophylla	TSHE	Western hemlock

Herbicide Reporting Form

Organization ____________

Reporter ____________

Address ____________ Phone ____________

Legal Description ____________

Habitat type ________ Slope (%) ________ Aspect ________ Elevation ________

Soil (texture and organic matter, if available) ____________

Herbicide Information	ADP Coding (do not write here)
Chemical ____________	____________
Rate (ai/acre) ____________	____________
Date applied ____________	____________
Method of application ____________	____________
Mode of application ____________	____________
Gallons of mix/acre ____________	____________
Adjuvants and % of total mix ____________	____________
Type of treatment	
If site preparation:	
did treatment precede planting? ____________	____________
time lapse? ____________	____________
did treatment follow planting? ____________	____________
time lapse? ____________	____________
were trees protected from chemical? ____________	____________
was treatment brown-burn? ____________	____________
time between chemical treat and burn ____________	____________
time between burn and planting ____________	____________

Target Species Information

Type of rating (check one):

ADP Coding
(Do not write here)

general observation ______

numerical rating scheme ______

Lapse time between treatment and rating (months) ______

Species Ratings

Species	Rating kill	Rating sprout	Species	Rating kill	Rating sprout
ACGL			RUBU		
ALSI			SALX		
AMAL			SAMB		
ARUV			SORB		
BEAQ			SPBE		
CARU			SYMP		
CARX			VACC		
CESA			XETE		
CEVE			Others		
CIRS			↓		
FORB					
GRAS					
HODI					
LOUT					
MEFE					
PAMY					
PHLE					
PHMA					
POTR					
PRUN					
PTAQ					
RHPU					
RIBE					
ROSA					
RUPA					

Conifer Damage Information

Species	Rating	Species	Rating	ADP Coding (Do not write here)

Time of rating (months since treatment) ______ ______

Conifer Response Information

Survival - Controls ______ % ______

Chem. Treated ______ % ______

Other ______ % ______

Year rated: 1st ____ 2nd ____ 3rd ____ Other ______

Growth - Controls ______ ______

Chem. Treatment ______ ______

Other ______ ______

Year rated: 1st ____ 2nd ____ 3rd ____ Other ______

Other information of interest (narrative):

*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-676-039/20025

Boyd, Raymond J.; Miller, Daniel L.; Kidd, Frank A.; Ritter, Catherine P. Herbicides for forest weed control in the Inland Northwest: a summary of effects on weeds and conifers. General Technical Report INT-195. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 66 p.

The effectiveness of various herbicide treatments on a variety of shrub and herbaceous competitive species and on crop conifers in the Inland Northwest is reported as an aid to silviculturists in evaluating alternative site preparation and conifer release treatments. Sources are provided for obtaining further information.

KEYWORDS: herbicides, effects, shrubs, herbs, conifers, Inland Northwest, site preparation, conifer release

The Intermountain Research Station, headquartered in Ogden, Utah, is one of eight Forest Service Research stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station's primary area includes Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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United States
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Agriculture

Forest Service

**Intermountain
Research Station
Ogden, UT 84401**

General Technical
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User's Guide to the Event Monitor: An Addition to the Prognosis Model

Nicholas L. Crookston

IF

PAI LT MAI

Then harvest, prepare site,

and plant Douglas-fir

THE AUTHOR

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RESEARCH SUMMARY

The Event Monitor is a programmed procedure for dynamically invoking management activities to be simulated by the Prognosis Model. Activities include simulated thinnings, harvesting, plantings, or any other activity that the simulation model can mimic. The Event Monitor accepts policy statements expressed as conditions to be met and a set of activities to be simulated after the conditions are met. Thus, policy statements may be evaluated using Prognosis Model without users foretelling the development of each stand in an analysis and manually scheduling activities.

The Event Monitor enhances control of the Prognosis Model and the operation of several model extensions, notably the Regeneration Establishment Model and the Parallel Processing Extensions (PPE). As a part of the PPE, the monitor can generate decision trees of management alternatives.

CONTENTS

User's Guide to the Event Monitor: An Addition to the Prognosis Model

Nicholas L. Crookston

INTRODUCTION

The decision to perform a management activity in a stand is often contingent upon several factors. Thinning may be called for if the stand is too dense, or spraying may be required if an insect population is causing too much damage. Usually, users of stand-growth simulation models must foretell when stand conditions that require management action will occur and preschedule the program options that represent those actions.

The Event Monitor offers an alternative method of scheduling activities: You specify a set of conditions that must occur, or thresholds that must be reached. During the simulation, the specified conditions are monitored and, in the event they occur, the management activities you specify are scheduled. For example, suppose you wish to schedule a thinning only if the stand crown competition factor (Krajicek and others 1961) exceeds 150, trees per acre exceed 500, and age is greater than 20 and less than 60 years. Using the Event Monitor, the conditions are specified via a logical expression followed by the activities (represented by Prognosis Model options) that are to be invoked when that expression is true.

Taken together, an event and the management activities may be viewed as a policy statement. Thus, policy statements may be evaluated using Prognosis Model without users foretelling the development of each stand in an analysis and manually scheduling activities.

The monitor is part of Version 5 of the Prognosis Model (Stage 1973; Wykoff and others 1982); as a component of that model, it serves the following purposes:

- Permits the inclusion of policy statements in a simulation run. Thus emphasis may be placed on the specification of a policy applicable to a class of stands, rather than on a prescription for individual stands.
- Offers an additional mechanism to control the operation of extensions to the Prognosis Model such as the Regeneration Establishment Model (Ferguson and Crookston 1984).
- Provides a way to create decision trees within the Parallel Processing Extension (Crookston in preparation). Decision trees are useful for systematically evaluating the response of forest growth to random catastrophic events (insect epidemics or forest fires, for example) and alternative management practices given equal starting conditions.

Specific examples will show how to use the program. The rules that govern its operation are implicitly presented in the examples and then explicitly presented in a subsequent section. This order is designed to give you a general understanding of the program's use before you are presented with specific

details. How you apply the rules to your own problems is left to your imagination. Be bold! If you can't find an example that meets your requirements, invent one.

I assume that you are familiar with the Prognosis Model. Terms, operational rules, and concepts explained in the Prognosis Model user's guide (Wykoff and others 1982) are used here without explanation.

USING THE EVENT MONITOR

Overview

An event is designated by an IF keyword record, followed by a logical expression. The expression is coded on one or more supplemental data records. It may contain constants, arithmetic operators, parentheses, relational and logical operators (greater than (GT), less than (LT), equal (EQ), AND, OR, etc.), and certain variables. Following the logical expression, a THEN keyword record is entered; it signals the end of the logical expression and the beginning of the activities that will be scheduled only when the expression is true. Any Prognosis Model keyword-option (including those found in extensions) that can be scheduled by entering a cycle number or year in the first numeric field can be scheduled by the Event Monitor. The value in Field 1 of the activity keyword record is added to the year the event occurs, the sum becomes the year the activity is scheduled to occur. An ENDIF keyword is entered to signal that normal activity processing should resume.

IF, THEN, and ENDIF

Example 1.—The example presented in the Introduction is elaborated on in the context of a complete Prognosis Model keyword file. The policy for this example is as follows: If before-thinning crown competition factor (BCCF) is greater than 150, before-thinning trees per acre (BTPA) is greater than 500, and age is greater than 20 and less than 60, then thin from below to a residual stand density of 300 trees per acre.

	Keyword record							
Reference line	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7
1	STANDID							
2	EXAMPLE1	EVENT MONITOR USER'S GUIDE EXAMPLE 1.						
3	INVYEAR	1972.						
4	NUMCYCLE	10.						
5	IF	999.						
6	BCCF GT 150 AND BTPA GT 500 AND AGE &							
7	GT 20 AND AGE LT 60							
8	THEN							
9	THINBTA	0.	300.					
10	ENDIF							
11	STDINFO	18.	710.	10.	4.	5.	56.	
12	PROCESS							
13	STOP							

Some of the output created by running this example is in the appendix; further explanation of the input file follows:

Lines 1 and 2: Enter the stand identification and a run title.

Line 3: Specify the inventory year.

Line 4: Specify the number of cycles.

Line 5: IF signals that a logical expression follows and that the minimum delay time between responses to this event is 999 years.

Lines 6 and 7: The logical expression is coded "free form" (that is, characters need not be placed in specific columns) on one or more supplemental data records that follow the IF keyword. The ampersand ("&") at the end of line 6 signals that the expression is continued on the following record.

Line 8: THEN signals that the activities (options specified by date or cycle) that follow will not be scheduled until after the event happens; that is, when the logical expression is true.

Line 9: THINBTA is a thinning option that will be scheduled in the same year that the event happens; thus, a zero is coded in field 1. The residual trees per acre are coded in field 2.

Line 10: ENDIF marks the end of the conditionally specified options.

Line 11: Enter data specific to the stand such as the forest code.

Line 12: Signals that all of the keywords have been entered and that the stand should be processed.

Line 13: Stop the Prognosis Model.

Minimum delay time.—It is possible to specify a logical expression that could remain true for several consecutive cycles. If you intend to schedule a response to the event on longer intervals than each succeeding cycle, you may enter a minimum number of years between responses in field 1 of the IF keyword.

Example 2.—This example illustrates:

- the Event Monitor's use with the Regeneration Establishment Model (Ferguson and Crookston 1984) and, by implication, other Prognosis Model extensions;
- that more than one activity may be specified after a THEN keyword;
- that more than one policy statement may be specified; and
- that the minimum delay time can be set to control the frequency at which activities are scheduled.

The first policy statement concerns the regeneration harvest guides and reads as follows: When the culmination of mean annual increment (MAI) is reached, clearcut the stand, broadcast burn the next year, and, in the second year after harvest, plant 300 spruce and 300 larch per acre. The date of culmination is detected by monitoring periodic annual increment (PAI, 10-year period) and MAI. When periodic annual increment (PAI) is less than MAI, the stand has reached culmination of MAI.

The second policy statement concerns scheduling some thinnings to control density: When the stand basal area (BBA) exceeds 150 ft^2 per acre, thin from below to 130 ft^2. These thinnings should not occur more frequently than every 20 years.

The keyword file used to run this example is listed below; output is in the appendix.

Reference line	Keyword record							
	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7
1	STANDID							
2	EXAMPLE2	EVENT MONITOR USER'S GUIDE, EXAMPLE 2						
3	INVYEAR	1972.						
4	NUMCYCLE	15.						
5	IF	999.						
6	PAI LT MAI							
7	THEN							
8	THINATA	0.	0.	1.				
9	ESTAB							
10	BURNPREP	1.	80.					
11	MECHPREP	1.	20.					
12	PLANT	2.	2.	300.	90.			
13	PLANT	2.	8.	300.	90.			
14	STOCKADJ	9.	−1.					
15	RESETAGE	0.	0.					
16	END							
17	ENDIF							
18	IF	20.						
19	BBA GT150 AND AGE LT 130							
20	THEN							
21	THINBBA	0.	130.					
22	ENDIF							
23	STDINFO	18.	680.	150.	8.	5.	53.	
24	PROCESS							
25	STOP							

Lines 1 to 4: Like example 1.

Line 5: Specify that the logical expression follows and that the minimum delay time between responses to this event is 999 years.

Lines 6 and 7: Specify the event: IF the PAI is less than the MAI, THEN.

Line 8: The management activity is to cut (using a Prognosis Model thinning option) all of the trees. Note that the residual stand density coded in field 2 is zero, and that the cutting effectiveness coded in field 3 is 1.0.

Line 9: Signals the Prognosis Model that Regeneration Establishment Model options follow.

Lines 10 through 15: Specify the site preparation assumptions and the plantings. Line 14 contains a command that limits establishment of trees to only those planted. Line 15 causes the stand age to be reset to zero years (the number coded in field 2). Consult Ferguson and Crookston (1984) for a complete description of these keywords.

Line 16: Signals the Establishment Model that Prognosis Model options follow.

Line 17: Signals the end of the activities that will only be scheduled when PAI is less than MAI.

Lines 18 to 22: A second policy is entered with a minimum delay time between responses set to 20 years (field 1 of line 18). The before-thin basal area is compared to 150, area is compared to 130 (line 19), and a thinning from below to 130 ft^2 is requested in line 21.

Generating Decision Trees

Decision trees are used to evaluate several different management responses to one event. For a description of this and other applications of decision trees see Stage (1975), Talerico and others (1978), Crookston (1978), Stage and others (in press), and the Parallel Processing Extension user's guide (PPE) (Crookston in preparation). Because the creation of decision trees (fig. 1) in the PPE is controlled by the Event Monitor, an example has been included to illustrate how to use the PPE and the Event Monitor together.

The branches of the decision tree are defined by specifying more than one group of activities following a single logical expression. The first activity (or activity group) follows the THEN keyword record; each subsequent group of activities follows an ALSOTRY keyword record. Each alternative group defines a branch of the decision tree. You may specify one to nine alternative groups of activities for each event. Remember, this option may only be used with the PPE.

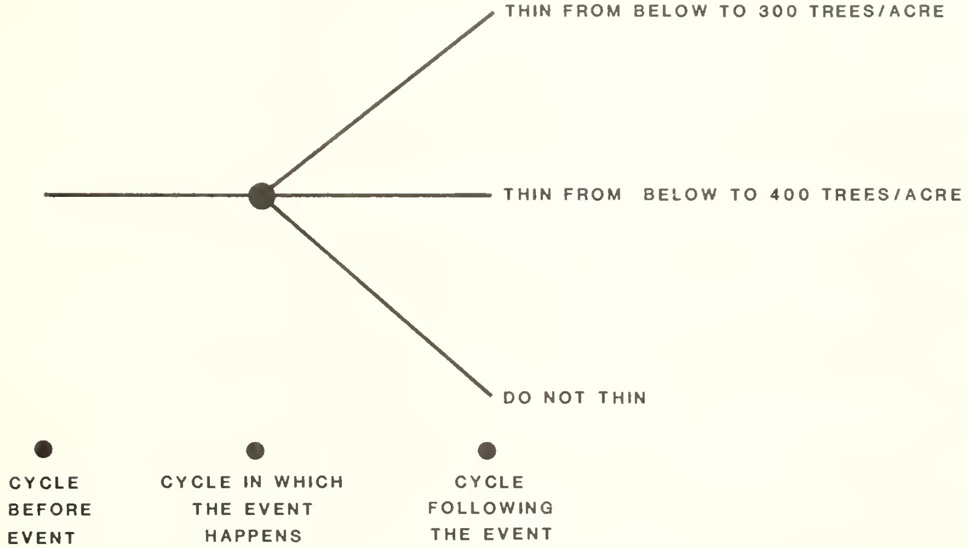

Figure 1.—The decision tree generated by the PPE when the logical expression in example 3 is true. The black circle is the ***node****; in this case three* ***branches*** *stem from the node.*

Example 3: ALSOTRY.—Let's reconsider example 1. A thinning from below to 300 trees per acre will be scheduled when the event happens. Using the PPE in conjunction with the Event Monitor you may ALSOTRY another alternative, say thinning from below to 400 trees per acre. A third alternative is not to thin at all. The PPE simulates and reports the results of trying all three alternatives. Keyword records needed to accomplish this objective are as follows (those needed in addition to example 1 are at lines 0.1, 9.1-9.3, and 12.1-12.3):

Reference line	Keyword	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7
	Keyword record							
0.1	ADDSTAND							
1	STANDID							
2	EXAMPLE3	EVENT MONITOR USER'S GUIDE EXAMPLE 3.						
3	INVYEAR	1972.						
4	NUMCYCLE	10.						
5	IF	999.						
6	BCCF GT 150 AND BTPA GT 500 AND AGE &							
7	GT 20 AND AGE LT 60							
8	THEN							
9	THINBTA	0.	300.					
9.1	ALSOTRY							
9.2	THINBTA	0.	400.					
9.3	ALSOTRY							
10	ENDIF							
11	STDINFO	18.	710.	10.	4.	5.	56.	
12	PROCESS							
12.1	PROJECT							
12.2	NOCOMPOS							
12.3	YIELDS							
13	STOP							

Output created by running this example may be found in the appendix. An explanation of the input file follows:

Line 0.1: ADDSTAND is a PPE keyword that signals that Prognosis Model keywords follow. See Crookston (in preparation) for an additional explanation.

Lines 1 through 9: Like example 1.

Line 9.1: ALSOTRY signals that another group of activity keywords follows.

Line 9.2: THINBTA is entered with a residual of 400 trees per acre.

Line 9.3: Another ALSOTRY that is followed immediately by an ENDIF signals that one alternative is no management.

Lines 10 through 12: Same as in example 1.

Line 12.1: PROJECT is a PPE keyword that signals that all of the stands (in this case there is only one stand) have been entered and the projection may start.

Line 12.2: NOCOMPOS is a PPE keyword that suppresses the calculation of the composite yield table.

Line 12.3: YIELDS is a PPE keyword that triggers the printing of the yield statistics.

Line 13: Same as in example 1.

You can see the results of the branching and scheduling by carefully reading the Activity Summary tables printed by the PPE for the three management alternatives (output is in the appendix). Each summary table corresponds to one branch of the decision tree (fig. 1). The Activity Summaries list the activities that were scheduled and accomplished and correspond with the Summary Statistics tables printed above them. Consult Wykoff and others (1982) for an additional description of these tables, and Crookston (in preparation) for a description of the PPE.

DETAILED INSTRUCTIONS

The first section of this report describes the purpose and potential use of the Event Monitor and its position within the Prognosis Model. The following section offers additional details that will enable you to make full use of the Event Monitor.

This section is organized as follows: a keyword summary describes the keywords used by the event monitor. A section titled "Order of Computations" will help you understand how the order of calculations within the Prognosis Model influences the Event Monitor. The rules you need to follow when coding logical expressions are described in a section called "Coding Logical Expressions."

Keyword Summary

IF — Signals that the logical expression follows on one or more supplemental data records. You may enter several policies by entering a set of IF, THEN, activity keywords, and an ENDIF for each policy.

Field 1: The minimum waiting time before the event may happen again, default is zero years.

THEN — Signals that the activities that follow will be scheduled when the event happens.[1]

ALSOTRY — Used in conjunction with the PPE to generate decision trees. Signals that a second or subsequent group of activities follow.[1]

ENDIF — Signals the end of a set of Event Monitor keywords.

Several program options that represent activities may follow one THEN or ALSOTRY keyword. (The actual number depends on many factors; a realistic upper limit is about 100.)

Any Prognosis Model options that may be scheduled (that is, a date or cycle is entered in field 1 of the keyword record), may alternatively be entered as conditional activities, that is, they may follow a THEN or ALSOTRY. Prognosis Model options that do not contain a date in field 1 may not be made conditional. For example, a NUMCYCLE keyword entered between a THEN and an ENDIF keyword will be processed normally.

Order of Computations

When expressions are evaluated.—The Event Monitor evaluates all logical expressions at each of two different times during a growth cycle (see fig. 1 in Wykoff and others 1982): once at the beginning of the growth cycle prior to thinnings, and once after thinnings. Therefore, a logical expression that tests on before-thin density can be used to trigger a thinning during the same cycle.

The Regeneration Establishment Model is called near the end of a cycle. Thus, it is possible to trigger a regeneration tally as a response to a before-thin or an after-thin density.

You can schedule a thinning in response to detecting that a thinning has occurred. However, the conditionally scheduled thinning cannot be simulated during the same cycle the event is detected because the event is, itself, another thinning. You can specify that the conditionally scheduled thinning be scheduled 10 years after the event occurs by coding "10" in field 1 of the desired thinning keyword record. If the cycle length is 10 years, the conditionally scheduled thinning will thus be simulated in the following cycle.

[1]The numeric fields on the THEN and ALSOTRY keywords are reserved for future use by the PPE.

When Event Monitor variables are defined.—The variables that can be used in logical expressions are divided into four groups (table 1) depending on when the variables are defined. If any variable is undefined when the expression is evaluated, the expression is deemed false.

Table 1.—Variables that can be used within logical expressions

Variable name	Description
	Group 1, always defined
YEAR	Beginning year of a cycle
AGE	Age at beginning of a cycle
BTPA	Before-thin trees per acre
BTCUFT	Before-thin total cubic foot volume
BMCUFT	Before-thin merchantable cubic foot volume
BBDFT	Before-thin Scribner board foot volume
BBA	Before-thin basal area per acre
BCCF	Before-thin crown competition factor
BCCFWP	Before-thin crown competition factor for white pine
BCCFL	Before-thin crown competition factor for larch
BCCFDF	Before-thin crown competition factor for Douglas-fir
BCCFGF	Before-thin crown competition factor for grand fir
BCCFWH	Before-thin crown competition factor for western hemlock
BCCFC	Before-thin crown competition factor for western redcedar
BCCFLP	Before-thin crown competition factor for lodgepole pine
BCCFS	Before-thin crown competition factor for spruce
BCCFAF	Before-thin crown competition factor for alpine fir
BCCFPP	Before-thin crown competition factor for ponderosa pine
BCCFOTR	Before-thin crown competition factor for other species
BTOPHT	Before-thin average top height
BADBH	Before-thin quadratic mean d.b.h.
RANN	A random number between 0 and 1
YES	The constant 1.
NO	The constant 0.
NUMTREES	Number of tree records stored by the model
CYCLE	Cycle number
	Group 2, defined only after thinning each cycle
ATPA	After-thin trees per acre
ATCUFT	After-thin total cubic foot volume
AMCUFT	After-thin merchantable cubic foot volume
ABDFT	After-thin Scribner board foot volume
ABA	After-thin basal area per acre
ACCF	After-thin crown competition factor
ACCFWP	After-thin crown competition factor for white pine
ACCFL	After-thin crown competition factor for larch
ACCFDF	After-thin crown competition factor for Douglas-fir
ACCFGF	After-thin crown competition factor for grand fir
ACCFWH	After-thin crown competition factor for western hemlock
ACCFC	After-thin crown competition factor for western redcedar
ACCFLP	After-thin crown competition factor for lodgepole pine
ACCFS	After-thin crown competition factor for spruce
ACCFAF	After-thin crown competition factor for alpine fir
ACCFPP	After-thin crown competition factor for ponderosa pine
ACCFOTR	After-thin crown competition factor for other species
ATOPHT	After-thin average top height
AADBH	After-thin quadratic mean d.b.h.
RTPA	Removed trees per acre
RTCUFT	Removed total cubic foot volume
RMBDFT	Removed Scribner board foot volume

(con.)

Table 1. (Con.)

Variable name	Description
	Group 3, defined when cycle 2 starts
ACC	Accretion from last cycle, cubic feet/acre/year
MORT	Mortality from last cycle, cubic feet/acre/year
PAI	Periodic annual increment last cycle, cubic feet per acre
MAI	Mean annual increment last cycle, cubic feet
DTPA	Number of trees per acre at the beginning of current cycle minus the number at the beginning of previous cycle
DTPA%	Trees per acre at the beginning of current cycle divided by the number at the beginning of previous cycle; then multiplied times 100
DBA	Basal area per acre at the beginning of current cycle minus the basal area at the beginning of previous cycle
DBA%	Basal area per acre at the beginning of current cycle divided by the basal area at the beginning of previous cycle; then multiplied times 100
DCCF	Crown competition factor at the beginning of current cycle minus the factor at the beginning of previous cycle
DCCF%	Crown competition factor at the beginning of current cycle divided by the factor at the beginning of previous cycle; then multiplied times 100
	Group 4, defined by extensions to the Prognosis Model
TM%STND	The stand average tree defoliation level caused by the Douglas-fir tussock moth during the previous cycle (Monserud and Crookston 1982)
TM%DF	The average tree defoliation on Douglas-fir
TM%GF	The average tree defoliation on grand fir
MPBTPAK	The number of trees per acre killed by the mountain pine beetle during the previous cycle
BW%STND	The stand defoliation level caused by the western spruce budworm during the previous cycle
SELECTED	Takes on the value YES if the stand has been selected for harvest by the PPE's harvest allocation logic. The value is NO if the stand has not been selected.

Variables listed in group 1 are always known; you can include them in logical expressions either by themselves or with those listed in the other groups.

Group 2 variables are only known after thinning. They are correctly defined even though no thinnings are done in a given cycle, but they are undefined when the Event Monitor evaluates expressions prior to thinnings each cycle.

Group 3 variables are not defined until after the first cycle. For example, the stand accretion is computed after the second time the Event Monitor evaluates logical expressions each cycle. Therefore, the stand accretion variable is assigned the accretion from the previous cycle. Variables that measure change, such as DBA (delta basal area, the change in basal area from cycle to cycle), are computed by the monitor by subtracting the value stored from the previous cycle from the current value. These variables are also undefined until the beginning of the second Prognosis Model cycle. After the second cycle starts, group 3 variables can be used any time.

Group 4 variables are assigned values by Prognosis Model extensions. The value of these variables remains unknown unless the appropriate extension is being used.

Coding Logical Expressions

Logical expressions consist of variables (table 1), constants, parentheses, and logical and arithmetic operators (table 2). When coding logical expressions, follow these rules:

- Variable names, constants, and function names must be separated from logical operators by one or more blanks or parentheses.
- A parenthesis, constant, or variable must separate two arithmetic operators: AGE*−2.5 is invalid, AGE*(−2.5) is valid, −2.5*AGE is also valid.
- Operators are executed in order of precedence given in table 2, or parentheses may be used to control the precedence of evaluation.
- When equally ranked operations are found, evaluation proceeds from left to right.
- Constants are treated as floating point numbers whether or not a decimal point is coded. A value coded as an integer is converted to floating point by adding decimal point: 300 is converted to 300.0.
- An ampersand (&) signals that the expression is continued on the next line. Characters that follow the ampersand are ignored and may be used to enter comments.

The following are **valid** (and equivalent) expressions:

```
(BTPA*2 GE  1000  OR  AGE  GT 50.)
(NOT BTPA LT 500)  OR  (NOT AGE LE 50.0)
NOT  (BTPA LT 500  AND  AGE LE 50)
```

The following are **invalid**:

(ATPA .LT. 500.)—the inclusion of the periods before and after the less-than operator is valid in FORTRAN but **not** in the Event Monitor.
(NOT ((BTPA LT 50))—unbalanced parentheses.

Table 2.—Operators that can be used in logical expressions

Precedence[1]	Operator	Description	Example of usage
		Arithmetic functions	
1^{st}	SQRT	Square root	SQRT(A)
1^{st}	EXP	e raised to power A	EXP(A)
1^{st}	ALOG	Natural logarithm	ALOG(A)
1^{st}	ALOG10	Common logarithm	ALOG10(A)
1^{st}	INT	Truncate fractional part[2]	INT(A/B)
1^{st}	FRAC	Truncate integer part[3]	FRAC(A/B)
		Arithmetic operators	
2^{nd}	−	Change sign	−A
3^{rd}	**	Exponentiate	A**B
4^{th}	*	Multiply	A*B
4^{th}	/	Divide	A/B
5^{th}	+	Add	A+B
5^{th}	−	Subtract	A−B
		Logical operators	
6^{th}	EQ	Equal	A EQ B
6^{th}	NE	Not equal	A NE B
6^{th}	LT	Less than	A LT B
6^{th}	GT	Greater than	A GT B
6^{th}	LE	Less than or equal	A LE B
6^{th}	GE	Greater than or equal	A GE B
7^{th}	NOT	Logical not	NOT (A GT B)
8^{th}	AND	Logical and	(A GT B) AND (A LT C)
9^{th}	OR	Logical or	(A GT B) OR (A LT C)

[1]Operators are executed in order of precedence within parenthetical groups. For example consider the following: ALOG(A)**2.+5/C, the log is taken first, the result is raised to the power of 2, then 5 is divided by C and added to the previous result.
[2]For example: INT(3.4) is equal to 3.0.
[3]For example: FRAC(3.4) is equal to 0.4.

SUMMARY

Using the Event Monitor, logical relations between stand variables generated by the Prognosis Model can be evaluated during the simulation. When the logical relation is true, activities which the model is capable of simulating will be invoked.

This document describes how to use the Event Monitor to schedule Prognosis Model options such as thinnings and Establishment Model options and how to create decision trees using the PPE.

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APPENDIX: OUTPUT EXAMPLES

Example 1.

```
                         STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.0 -- INLAND EMPIRE (TEST)
----------------------------------------------------------------------------------------------------

                                        OPTIONS SELECTED BY INPUT

----------------------------------------------------------------------------------------------------
KEYWORD     PARAMETERS:
--------    ----------------------------------------------------------------------------------------

STDIDENT
            STAND ID= EXAMPLE1            EVENT MONITOR USER'S GUIDE EXAMPLE 1.

INVYEAR     INVENTORY YEAR= 1972

NUMCYCLE    NUMBER OF CYCLES= 10

IF          MINIMUM DELAY TIME BETWEEN RESPONSES TO THE EVENT =   999

              BCCF GT 150 AND BTPA GT 500 AND AGE &
              GT 20 AND AGE LT 60

THEN        ACTIVITIES WHICH FOLLOW WILL NOT BE SCHEDULED UNTIL THE EVENT HAPPENS (WHEN THE LOGICAL EXPRESSION IS TRUE).

THINBTA     DATE/CYCLE=    0; RESIDUAL=  300.00; PROPORTION OF SELECTED TREES REMOVED= 0.980
            DBH OF REMOVED TREES WILL RANGE FROM   0.0 TO 999.0 INCHES

ENDIF       ACTIVITIES WHICH FOLLOW WILL BE SCHEDULED.

STDINFO     FOREST CODE= 18; HABITAT TYPE=710; AGE=   10; ASPECT CODE=  4.; SLOPE CODE=  5.
            ELEVATION(100'S FEET)= 56.0; SITE INDEX=   0.

PROCESS     PROCESS THE STAND.
----------------------------------------------------------------------------------------------------

                                        OPTIONS SELECTED BY DEFAULT

----------------------------------------------------------------------------------------------------

TREEFMT     (23X,I4,3X, F2.0,I1, A3.F3.1,F2.1,3X,F3.0,T63,F3.0   ,T60,F3.1,T48,  I1,3X, I2,
            2I1,T66,2I1,I3, 2I1)

DESIGN      BASAL AREA FACTOR= 40.0; INVERSE OF FIXED PLOT AREA=  300.0; BREAK DBH=    5.0
            NUMBER OF PLOTS=    18; NON-STOCKABLE PLOTS=     7; STAND SAMPLING WEIGHT=  18.00000
            STAND ATTRIBUTES ARE CALCULATED PER ACRE OF STOCKABLE AREA.  STAND STATISTICS
            IN SUMMARY TABLE ARE MULTIPLIED BY 0.611 TO INCLUDE TOTAL STAND AREA.

----------------------------------------------------------------------------------------------------
```

```
STAND ID= EXAMPLE1    MANAGEMENT ID= NONE        EVENT MONITOR USER'S GUIDE EXAMPLE 1.

----------------------------------------------------------------------------------------------------

CYCLE  DATE  EXTENSION  KEYWORD   DATE  PARAMETERS:
-----  ----  ---------  --------  ----  ------------------------------------------------------------

    1  1972
    2  1982
    3  1992
    4  2002
    5  2012
    6  2022
    7  2032
    8  2042
    9  2052
   10  2062
----------------------------------------------------------------------------------------------------
```

CALIBRATION STATISTICS:

	LP	WP	AF	--	S
NUMBER OF RECORDS PER SPECIES	2	5	19	5	2
NUMBER OF RECORDS CODED AS RECENT MORTALITY	0	0	0	0	0
NUMBER OF RECORDS WITH MISSING HEIGHTS	0	0	1	1	0
NUMBER OF RECORDS WITH BROKEN OR DEAD TOPS	0	0	0	0	0
NUMBER OF RECORDS WITH MISSING CROWN RATIOS	0	0	0	0	0
NUMBER OF RECORDS AVAILABLE FOR SCALING THE DIAMETER INCREMENT MODEL	0	0	1	0	1
RATIO OF STANDARD ERRORS (INPUT DBH GROWTH DATA : MODEL)	1.00	1.00	1.00	1.00	1.00
WEIGHT GIVEN TO THE INPUT GROWTH DATA WHEN DBH GROWTH MODEL SCALE FACTORS WERE COMPUTED	0.00	0.00	0.00	0.00	0.00
INITIAL SCALE FACTORS FOR THE DBH INCREMENT MODEL	1.00	1.00	1.00	1.00	1.00
NUMBER OF RECORDS AVAILABLE FOR SCALING THE SMALL TREE HEIGHT INCREMENT MODEL	0	0	0	0	0
INITIAL SCALE FACTORS FOR THE SMALL TREE HEIGHT INCREMENT MODEL	1.00	1.00	1.00	1.00	1.00

(con.)

Example 1. (Con.)

```
                           STAND GROWTH PROGNOSIS SYSTEM        VERSION 5.0 -- INLAND EMPIRE (TEST)

STAND ID: EXAMPLE1    MANAGEMENT CODE: NONE      EVENT MONITOR USER'S GUIDE EXAMPLE 1.

                                        STAND COMPOSITION (BASED ON STOCKABLE AREA)
----------------------------------------------------------------------------------------------------------------------
                           PERCENTILE POINTS IN THE
                       DISTRIBUTION OF STAND ATTRIBUTES BY DBH    TOTAL/ACRE
        STAND          ---------------------------------------     OF STAND       DISTRIBUTION OF STAND ATTRIBUTES BY
YEAR  ATTRIBUTES         10     30     50     70     90    100    ATTRIBUTES     SPECIES AND 3 USER-DEFINED SUBCLASSES
----  -----------      ------ ------ ------ ------ ------ ------ -------------  ---------------------------------------
                                    (DBH IN INCHES)


1972  TREES             0.1    0.1    0.1    0.1    0.1   19.9   1916. TREES    70.% AF2,  11.% AF1,   4.% --1,   4.% WP1
      VOLUME:
        TOTAL          11.2   11.2   19.9   19.9   19.9   19.9    161. CUFT     63.%  S2,  37.% AF2,   0.% AF1,   0.% --1
        MERCH          11.2   11.2   19.9   19.9   19.9   19.9    137. CUFT     62.%  S2,  38.% AF2,   0.% ---,   0.% ---
        MERCH          11.2   19.9   19.9   19.9   19.9   19.9    777. BDFT     70.%  S2,  30.% AF2,   0.% ---,   0.% ---

      ACCRETION         0.1    0.1    3.2   11.2   19.9   19.9     14. CUFT/YR  62.% AF2,  34.%  S2,   1.% AF1,   1.% --2
      MORTALITY         0.1    0.1    0.1    3.2   19.9   19.9      0. CUFT/YR  72.% AF2,  21.%  S2,   6.% AF1,   0.% --1


1982  TREES             0.1    0.7    0.8    1.2    1.5   23.1   1654. TREES    70.% AF2,  11.% AF1,   4.% --1,   4.% WP1
      VOLUME:
        TOTAL           1.4    6.2   12.8   21.4   23.1   23.1    297. CUFT     50.%  S2,  49.% AF2,   1.% AF1,   0.% --2
        MERCH          12.8   14.6   20.6   21.4   23.1   23.1    188. CUFT     57.%  S2,  43.% AF2,   0.% ---,   0.% ---
        MERCH          12.8   14.6   21.4   21.4   23.1   23.1   1095. BDFT     65.%  S2,  35.% AF2,   0.% ---,   0.% ---

      ACCRETION         0.9    1.4    1.5    4.0   12.8   23.1     35. CUFT/YR  72.% AF2,  21.%  S2,   2.% AF1,   2.% WP2
      MORTALITY         0.7    0.9    1.2    1.5   12.8   23.1      1. CUFT/YR  75.% AF2,  12.%  S2,   6.% AF1,   2.% --2


1992  TREES             0.8    1.2    2.0    2.4    3.6   26.2   1401. TREES    72.% AF2,  11.% AF1,   4.% --1,   4.% WP1
      VOLUME:
        TOTAL           2.2    3.3    6.6   15.3   23.7   26.2    644. CUFT     61.% AF2,  34.%  S2,   2.% AF1,   1.% WP2
        MERCH           8.2   14.4   16.2   22.9   24.6   26.2    287. CUFT     59.%  S2,  41.% AF2,   0.% ---,   0.% ---
        MERCH          13.5   16.1   22.1   22.9   24.6   26.2   1583. BDFT     64.%  S2,  36.% AF2,   0.% ---,   0.% ---

      ACCRETION         1.6    2.7    3.3    3.6   14.4   26.2     56. CUFT/YR  75.% AF2,  16.%  S2,   2.% AF1,   2.% WP2
      MORTALITY         1.2    2.2    3.3    3.6   21.3   26.2      3. CUFT/YR  68.% AF2,  18.%  S2,   5.% AF1,   2.% --2
```

(con.)

2002	TREES	1.5	2.2	3.2	4.0	5.2	27.5	1222.	TREES	73.% AF2,	10.% AF1,	3.% --1,	3.% WP1
	VOLUME:												
	TOTAL	3.2	4.9	5.2	10.8	25.1	27.5	1175.	CUFT	68.% AF2,	26.% S2,	2.% AF1,	2.% WP2
	MERCH	8.2	14.3	19.3	24.0	25.3	27.5	434.	CUFT	63.% S2,	37.% AF2,	0.% ---,	0.% ---
	MERCH	10.3	15.7	19.6	25.1	25.3	27.5	2332.	BDFT	64.% S2,	36.% AF2,	0.% ---,	0.% ---
	ACCRETION	3.2	3.8	4.9	5.7	11.8	27.5	80.	CUFT/YR	78.% AF2,	14.% S2,	4.% WP2,	2.% AF1
	MORTALITY	2.3	3.3	4.9	6.4	19.6	27.5	10.	CUFT/YR	69.% AF2,	19.% S2,	4.% AF1,	3.% WP2
2012	TREES	1.9	2.8	4.3	5.8	6.3	28.6	1047.	TREES	75.% AF2,	9.% AF1,	3.% WP1,	3.% --1
	VOLUME:												
	TOTAL	4.3	5.8	5.9	9.6	22.6	28.6	1879.	CUFT	72.% AF2,	21.% S2,	2.% WP2,	2.% AF1
	MERCH	8.6	9.6	14.3	21.1	26.3	28.6	761.	CUFT	52.% AF2,	48.% S2,	0.% ---,	0.% ---
	MERCH	9.6	12.2	17.5	22.6	26.6	28.6	3982.	BDFT	51.% S2,	49.% AF2,	0.% ---,	0.% ---
	REMOVAL	2.1	3.0	4.3	5.7	5.9	6.3	747.	TREES	92.% AF2,	4.% WP2,	3.% --2,	1.% LP2
	VOLUME:												
	TOTAL	3.4	5.1	5.7	5.9	5.9	6.3	870.	CUFT	94.% AF2,	5.% WP2,	1.% LP2,	0.% --2
	MERCH	0.0	0.0	0.0	0.0	0.0	6.3	0.	CUFT	0.% ---,	0.% ---,	0.% ---,	0.% ---
	MERCH	0.0	0.0	0.0	0.0	0.0	6.3	0.	BDFT	0.% ---,	0.% ---,	0.% ---,	0.% ---
	RESIDUAL	1.6	2.4	3.3	6.6	9.6	28.6	300.	TREES	33.% AF1,	32.% AF2,	12.% WP1,	10.% --1
	ACCRETION	4.4	9.6	9.6	9.6	14.3	28.6	75.	CUFT/YR	68.% AF2,	20.% S2,	6.% AF1,	3.% WP1
	MORTALITY	2.8	5.2	9.6	14.3	25.0	28.6	5.	CUFT/YR	41.% AF2,	29.% S2,	12.% AF1,	8.% WP1
2022	TREES	2.7	4.1	5.5	7.9	15.4	30.7	253.	TREES	37.% AF2,	31.% AF1,	10.% WP1,	10.% S2
	VOLUME:												
	TOTAL	7.7	12.5	15.4	15.4	26.2	30.7	1714.	CUFT	60.% AF2,	31.% S2,	4.% AF1,	2.% WP1
	MERCH	9.0	15.4	15.4	15.6	28.2	30.7	1425.	CUFT	64.% AF2,	35.% S2,	0.% AF1,	0.% WP2
	MERCH	11.1	15.4	15.4	18.3	28.2	30.7	7415.	BDFT	60.% AF2,	39.% S2,	0.% AF1,	0.% WP2
	ACCRETION	4.9	9.0	15.1	15.4	16.4	30.7	62.	CUFT/YR	57.% AF2,	25.% S2,	9.% AF1,	5.% WP1
	MORTALITY	5.3	9.0	15.4	15.4	23.8	30.7	9.	CUFT/YR	58.% AF2,	26.% S2,	7.% AF1,	4.% LP1
2032	TREES	3.6	5.3	7.1	11.4	17.0	31.8	230.	TREES	38.% AF2,	31.% AF1,	10.% S2,	10.% WP1
	VOLUME:												
	TOTAL	7.5	14.1	17.0	17.0	24.6	31.8	2248.	CUFT	59.% AF2,	29.% S2,	6.% AF1,	3.% WP1
	MERCH	8.7	16.3	17.0	17.0	27.4	31.8	1920.	CUFT	63.% AF2,	32.% S2,	2.% AF1,	1.% LP1
	MERCH	11.4	16.5	17.0	17.0	29.0	31.8	10096.	BDFT	60.% AF2,	38.% S2,	1.% AF1,	1.% LP1
	ACCRETION	6.2	8.7	16.5	17.0	17.0	31.8	81.	CUFT/YR	70.% AF2,	14.% S2,	10.% AF1,	4.% WP1
	MORTALITY	6.0	8.7	16.9	17.0	23.8	31.8	18.	CUFT/YR	59.% AF2,	24.% S2,	8.% AF1,	5.% WP1

(con.)

Example 1. (Con.)

2042	TREES	4.7	6.4	9.2	13.8	19.2	32.2	200.	TREES	39.% AF2,	30.% AF1,	11.% S2,	10.% WP1
	VOLUME:												
	TOTAL	8.1	14.3	19.2	19.2	24.9	32.2	2873.	CUFT	62.% AF2,	25.% S2,	7.% AF1,	3.% WP1
	MERCH	11.0	14.7	19.2	19.2	25.2	32.2	2528.	CUFT	66.% AF2,	27.% S2,	3.% AF1,	2.% LP1
	MERCH	11.9	15.2	19.2	19.2	28.6	32.2	13325.	BDFT	63.% AF2,	32.% S2,	3.% AF1,	1.% WP1
	ACCRETION	7.8	13.8	19.2	19.2	19.2	32.2	86.	CUFT/YR	70.% AF2,	14.% S2,	10.% AF1,	3.% WP1
	MORTALITY	6.7	11.9	17.5	19.2	24.9	32.2	24.	CUFT/YR	56.% AF2,	24.% S2,	9.% AF1,	6.% WP1
2052	TREES	5.9	7.6	11.0	15.6	21.6	33.4	176.	TREES	41.% AF2,	30.% AF1,	12.% S2,	9.% WP1
	VOLUME:												
	TOTAL	9.3	15.6	21.6	21.6	25.1	33.4	3496.	CUFT	65.% AF2,	23.% S2,	7.% AF1,	3.% WP1
	MERCH	11.0	16.4	21.6	21.6	25.7	33.4	3178.	CUFT	67.% AF2,	23.% S2,	5.% AF1,	2.% WP1
	MERCH	12.7	18.3	21.6	21.6	25.7	33.4	19178.	BDFT	69.% AF2,	24.% S2,	4.% AF1,	1.% WP1
	ACCRETION	8.9	15.6	21.6	21.6	21.6	33.4	99.	CUFT/YR	71.% AF2,	13.% S2,	10.% AF1,	3.% WP1
	MORTALITY	7.8	12.7	19.0	21.6	23.2	33.4	35.	CUFT/YR	61.% AF2,	20.% S2,	9.% AF1,	5.% WP1
2062	TREES	6.6	8.9	12.0	18.2	24.3	35.1	152.	TREES	42.% AF2,	30.% AF1,	12.% S2,	8.% WP1
	VOLUME:												
	TOTAL	10.8	18.1	24.3	24.3	24.3	35.1	4141.	CUFT	66.% AF2,	20.% S2,	8.% AF1,	3.% WP1
	MERCH	12.0	18.2	24.3	24.3	24.3	35.1	3851.	CUFT	68.% AF2,	21.% S2,	7.% AF1,	2.% WP1
	MERCH	12.3	18.2	24.3	24.3	24.3	35.1	22021.	BDFT	68.% AF2,	23.% S2,	5.% AF1,	2.% WP1
	ACCRETION	9.9	15.6	18.3	24.3	24.3	35.1	82.	CUFT/YR	68.% AF2,	14.% S2,	12.% AF1,	3.% WP1
	MORTALITY	8.3	13.8	20.4	24.3	24.3	35.1	33.	CUFT/YR	60.% AF2,	18.% S2,	11.% AF1,	6.% WP1
2072	TREES	7.6	10.3	13.3	20.0	25.7	35.7	134.	TREES	44.% AF2,	29.% AF1,	13.% S2,	8.% WP1
	VOLUME:												
	TOTAL	11.5	18.8	25.7	25.7	25.7	35.7	4624.	CUFT	67.% AF2,	19.% S2,	8.% AF1,	3.% WP1
	MERCH	12.4	19.4	25.7	25.7	25.7	35.7	4357.	CUFT	68.% AF2,	20.% S2,	8.% AF1,	2.% WP1
	MERCH	13.2	20.0	25.7	25.7	25.7	35.7	24626.	BDFT	68.% AF2,	22.% S2,	6.% AF1,	2.% WP1

(con.)

STAND GROWTH PROGNOSIS SYSTEM VERSION 5.0 -- INLAND EMPIRE (TEST)

STAND ID; EXAMPLE1 MANAGEMENT CODE: NONE EVENT MONITOR USER'S GUIDE EXAMPLE 1.

	ATTRIBUTES OF SELECTED SAMPLE TREES								ADDITIONAL STAND ATTRIBUTES (BASED ON STOCKABLE AREA)					
YEAR	INITIAL TREES/A %TILE	SPECIES	DBH (INCHES)	HEIGHT (FEET)	LIVE CROWN RATIO	PAST DBH GROWTH (INCHES)	BASAL AREA %TILE	TREES PER ACRE	STAND AGE	QUADRATIC MEAN DBH (INCHES)	TREES PER ACRE	BASAL AREA (SQFT/A)	TOP HEIGHT LARGEST 40/A (FT)	CROWN COMP FACTOR
1972						(10 YRS)								
	10	LP1	0.10	2.00	35	0.00	0.1	27.27						
	30	AF2	0.10	4.62	45	0.09	0.5	545.45						
	50	AF2	0.10	1.00	45	0.00	0.8	272.73						
	70	AF2	0.10	2.00	55	0.00	1.0	327.27						
	90	WP1	0.10	1.00	45	0.00	1.1	27.27						
	100	S2	19.90	70.00	65	2.30	100.0	1.68						
									10	0.9	1916.	9.	18.9	8.5
1982						(10 YRS)								
	10	LP1	0.82	6.16	35	0.70	5.8	22.11						
	30	AF2	1.50	10.77	45	1.31	37.7	472.89						
	50	AF2	0.10	3.03	45	0.00	0.0	236.45						
	70	AF2	0.89	7.07	55	0.74	10.1	283.74						
	90	WP1	0.10	4.21	45	0.00	0.1	22.67						
	100	S2	21.44	73.62	65	1.48	94.2	1.68						
									20	1.5	1654.	21.	25.1	27.7
1992						(10 YRS)								
	10	LP1	1.61	11.51	35	0.77	7.4	16.94						
	30	AF2	3.26	16.77	60	1.65	49.6	451.65						
	50	AF2	0.96	7.54	45	0.80	2.1	183.30						
	70	AF2	2.17	13.13	55	1.20	16.8	241.64						
	90	WP1	1.68	13.65	45	1.52	8.2	16.32						
	100	S2	22.91	77.02	65	1.40	95.5	1.68						
									30	2.7	1401.	54.	31.2	74.1
2002						(10 YRS)								
	10	LP1	3.05	21.16	56	1.39	13.2	13.34						
	30	AF2	4.93	19.72	64	1.56	56.1	433.12						
	50	AF2	1.74	11.34	45	0.74	2.8	153.01						
	70	AF2	3.20	17.00	84	0.96	18.2	224.83						
	90	WP1	2.92	19.72	45	1.20	10.2	15.34						
	100	S2	25.06	80.66	66	2.06	97.7	1.64						
									40	3.9	1222.	101.	36.5	132.2
2012						(10 YRS)								
	10	LP1	4.31	26.34	56	1.22	12.4	11.98						
	30	AF2	5.90	24.45	57	0.91	59.5	400.35						
	50	AF2	2.71	16.38	45	0.90	4.8	124.77						
	70	AF2	5.72	20.41	85	2.36	34.2	199.24						
	90	WP1	3.34	24.82	63	0.41	9.1	13.65						
	100	S2	26.32	83.61	59	1.20	98.5	1.55						
									50	5.2	1047.	152.	37.7	189.3
									RESIDUAL:	6.5	300.	69.	37.7	73.3

(con.)

Example 1. (Con.)

2022						(10 YRS)								
	10	LP1	5.95	33.60	59	1.60	10.0	10.81						
	30	AF2	6.46	28.94	60	0.52	11.5	7.28						
	50	AF2	3.68	18.43	46	0.91	2.5	2.19						
	70	AF2	7.28	27.71	87	1.46	12.0	3.84						
	90	WP1	4.96	32.30	66	1.56	7.6	9.80						
	100	S2	28.20	86.81	65	1.80	98.2	1.50	60	9.0	253.	113.	41.5	114.2
2032						(10 YRS)								
	10	LP1	7.07	38.56	58	1.08	11.0	10.07						
	30	AF2	7.48	33.84	57	0.96	12.4	5.99						
	50	AF2	5.26	24.00	44	1.49	4.5	1.90						
	70	AF2	11.97	34.44	90	4.39	29.5	3.61						
	90	WP1	5.96	39.15	64	0.96	7.7	9.13						
	100	S2	29.75	89.70	62	1.48	99.2	1.44	70	10.4	230.	137.	45.7	134.0
2042						(10 YRS)								
	10	LP1	8.01	43.15	56	0.91	11.6	8.82						
	30	AF2	8.12	38.66	53	0.60	12.0	5.39						
	50	AF2	6.51	27.32	42	1.17	5.5	1.75						
	70	AF2	13.72	40.07	86	1.64	28.7	3.40						
	90	WP1	6.52	44.89	62	0.54	6.1	7.86						
	100	S2	31.40	92.53	59	1.58	99.7	1.35	80	12.2	200.	162.	51.0	155.4
2052						(10 YRS)								
	10	LP1	9.12	47.89	55	1.07	10.7	7.43						
	30	AF2	8.72	43.20	50	0.56	9.1	4.49						
	50	AF2	6.89	31.65	38	0.36	3.7	1.58						
	70	AF2	15.87	46.01	84	2.02	34.3	3.14						
	90	WP1	7.17	49.85	61	0.62	5.1	5.96						
	100	S2	32.76	95.10	57	1.30	99.7	1.26	90	13.8	176.	182.	56.3	171.0
2062						(10 YRS)								
	10	LP1	10.59	52.93	54	1.42	11.2	6.47						
	30	AF2	9.68	48.23	48	0.90	8.3	3.69						
	50	AF2	7.62	35.50	36	0.68	2.8	1.18						
	70	AF2	18.09	51.90	82	2.08	33.3	2.87						
	90	WP1	7.70	55.34	60	0.51	3.2	4.64						
	100	S2	35.11	98.01	55	2.25	100.0	1.15	100	15.5	152.	200.	61.6	183.8
2072						(10 YRS)								
	10	LP1	10.91	56.05	52	0.31	8.4	5.94						
	30	AF2	10.31	52.58	47	0.59	7.1	3.26						
	50	AF2	8.37	40.23	35	0.70	2.9	0.98						
	70	AF2	19.69	57.11	81	1.50	35.1	2.67						
	90	WP1	8.67	61.05	60	0.94	3.7	3.44						
	100	S2	35.72	99.95	54	0.59	100.0	1.07	110	16.9	134.	210.	65.8	189.6

```
STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.0 -- INLAND EMPIRE (TEST)

                          SUMMARY STATISTICS (BASED ON TOTAL STAND AREA)
---------------------------------------------------------------------------------------------------------
                     VOLUME PER ACRE        REMOVALS PER ACRE                    GROWTH
                  -----------------  -----------------------  BA/     TOP  ------------ STAND   IDENTIFIERS
           TREES TOTAL MERCH MERCH TREES TOTAL MERCH MERCH ACRE      HT   PRD ACC MOR SAMPLE  -------------
YEAR AGE  /ACRE CU FT CU FT BD FT /ACRE CU FT CU FT BD FT SQFT CCF FT   YRS CUFT/YR WEIGHT   STAND    MGMT
---- ---  ----- ----- ----- ----- ----- ----- ----- ----- ---- --- ---  --- --- --- ------ --------- ----
1972  10   1171    98    84   475     0     0     0     0    5   5  19   10   8   0     18 EXAMPLE1  NONE
1982  20   1011   181   115   669     0     0     0     0   13  17  25   10  22   0     18 EXAMPLE1  NONE
1992  30    856   393   175   967     0     0     0     0   33  45  31   10  34   2     18 EXAMPLE1  NONE
2002  40    747   718   265  1425     0     0     0     0   62  81  36   10  49   6     18 EXAMPLE1  NONE
2012  50    640  1149   465  2433   457   532     0     0   42  45  38   10  46   3     18 EXAMPLE1  NONE
2022  60    155  1048   871  4531     0     0     0     0   69  70  41   10  38   5     18 EXAMPLE1  NONE
2032  70    141  1374  1173  6170     0     0     0     0   83  82  46   10  49  11     18 EXAMPLE1  NONE
2042  80    122  1756  1545  8143     0     0     0     0   99  95  51   10  52  14     18 EXAMPLE1  NONE
2052  90    108  2136  1942 11720     0     0     0     0  111 105  56   10  61  21     18 EXAMPLE1  NONE
2062 100     93  2531  2354 13457     0     0     0     0  122 112  62   10  50  20     18 EXAMPLE1  NONE
2072 110     82  2825  2663 15049     0     0     0     0  128 116  66    0   0   0     18 EXAMPLE1  NONE


                                     ACTIVITY SUMMARY

STAND ID= EXAMPLE1    MANAGEMENT ID= NONE       EVENT MONITOR USER'S GUIDE EXAMPLE 1.

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CYCLE  DATE  EXTENSION  KEYWORD   DATE  ACTIVITY DISPOSITION  PARAMETERS:
-----  ----  ---------  --------  ----  --------------------  ------------------------------------------------------

    1  1972
    2  1982
    3  1992
    4  2002

    5  2012
               BASE     THINBTA   2012  DONE IN 2012              300.00       0.98       0.00     999.00

    6  2022
    7  2032
    8  2042
    9  2052
   10  2062
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Example 2.

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                         STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.1 -- INLAND EMPIRE
--------------------------------------------------------------------------------------------------------------
                                          OPTIONS SELECTED BY INPUT
--------------------------------------------------------------------------------------------------------------
KEYWORD     PARAMETERS:
--------    ------------------------------------------------------------------------------------------------

STDIDENT
            STAND ID= EXAMPLE2            EVENT MONITOR USER'S GUIDE, EXAMPLE 2

INVYEAR     INVENTORY YEAR= 1972

NUMCYCLE    NUMBER OF CYCLES= 15

IF          MINIMUM DELAY TIME BETWEEN RESPONSES TO THE EVENT =   999

            PAI LT MAI

THEN        ACTIVITIES WHICH FOLLOW WILL NOT BE SCHEDULED UNTIL THE EVENT HAPPENS (WHEN THE LOGICAL EXPRESSION IS TRUE).

THINATA     DATE/CYCLE=    0; RESIDUAL=    0.00; PROPORTION OF SELECTED TREES REMOVED= 1.000
            DBH OF REMOVED TREES WILL RANGE FROM   0.0 TO 999.0 INCHES

ESTAB       REGENERATION ESTABLISHMENT OPTIONS:

BURNPREP    DATE/CYCLE=    1; % GROUND=  80.0

MECHPREP    DATE/CYCLE=    1; % GROUND=  20.0

PLANT       DATE/CYCLE=    2; SPECIES= 2.; TREES/ACRE=  300.; % SURVIVAL= 90.00

PLANT       DATE/CYCLE=    2; SPECIES= 8.; TREES/ACRE=  300.; % SURVIVAL= 90.00

STOCKADJ    DATE/CYCLE=    9; MULTIPLIER= -1.00
            NATURAL REGENERATION IS CANCELLED -- ONLY PLANTED TREES ARE TALLIED.

RESETAGE    DATE/CYCLE=    0; NEW AGE=    0.

END         REGENERATION TALLY ONE SCHEDULED FOR 9, AND TALLY TWO FOR 19 YEARS AFTER IF-EVENT IS TRUE.
            END OF ESTABLISHMENT KEYWORDS

ENDIF       ACTIVITIES WHICH FOLLOW WILL BE SCHEDULED.

IF          MINIMUM DELAY TIME BETWEEN RESPONSES TO THE EVENT =    20

            BBA GT 150 AND AGE LT 130

THEN        ACTIVITIES WHICH FOLLOW WILL NOT BE SCHEDULED UNTIL THE EVENT HAPPENS (WHEN THE LOGICAL EXPRESSION IS TRUE).

THINBBA     DATE/CYCLE=    0; RESIDUAL=  130.00; PROPORTION OF SELECTED TREES REMOVED= 0.980
            DBH OF REMOVED TREES WILL RANGE FROM   0.0 TO 999.0 INCHES

ENDIF       ACTIVITIES WHICH FOLLOW WILL BE SCHEDULED.

STDINFO     FOREST CODE= 18; HABITAT TYPE=680; AGE=  150; ASPECT CODE=  8.; SLOPE CODE=  5.
            ELEVATION(100'S FEET)= 53.0; SITE INDEX=   0.

PROCESS     PROCESS THE STAND.
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(con.)

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                              OPTIONS SELECTED BY DEFAULT

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TREEFMT     (23X,I4,3X, F2.0,I1, A3,F3.1,F2.1,3X,F3.0,T63,F3.0   ,T60,F3.1,T48,  I1,3X, I2,
            2I1,T66,2I1,I3, 2I1)

DESIGN      BASAL AREA FACTOR= 40.0; INVERSE OF FIXED PLOT AREA=  300.0; BREAK DBH=    5.0
            NUMBER OF PLOTS=     9; NON-STOCKABLE PLOTS=     0; STAND SAMPLING WEIGHT=   9.00000

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                                   ACTIVITY SCHEDULE

STAND ID= EXAMPLE2    MANAGEMENT ID= NONE      EVENT MONITOR USER'S GUIDE, EXAMPLE 2

--------------------------------------------------------------------------------------

CYCLE  DATE  EXTENSION  KEYWORD   DATE  PARAMETERS:
-----  ----  ---------  --------  ----  ----------------------------------------------

    1  1972
    2  1982
    3  1992
    4  2002
    5  2012
    6  2022
    7  2032
    8  2042
    9  2052
   10  2062
   11  2072
   12  2082
   13  2092
   14  2102
   15  2112
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(con.)

Example 2. (Con.)

CALIBRATION STATISTICS:

	DF	WP	S	GF	AF	LP	L
NUMBER OF RECORDS PER SPECIES	19	6	2	5	6	2	3
NUMBER OF RECORDS CODED AS RECENT MORTALITY	0	0	0	0	0	0	0
NUMBER OF RECORDS WITH MISSING HEIGHTS	0	0	0	0	0	0	0
NUMBER OF RECORDS WITH BROKEN OR DEAD TOPS	0	0	1	0	0	0	0
NUMBER OF RECORDS WITH MISSING CROWN RATIOS	0	0	0	0	0	0	0
NUMBER OF RECORDS AVAILABLE FOR SCALING THE DIAMETER INCREMENT MODEL	18	5	2	3	4	2	3
RATIO OF STANDARD ERRORS (INPUT DBH GROWTH DATA : MODEL)	1.12	1.17	1.00	1.00	1.00	1.00	1.00
WEIGHT GIVEN TO THE INPUT GROWTH DATA WHEN DBH GROWTH MODEL SCALE FACTORS WERE COMPUTED	0.73	0.89	0.00	0.00	0.00	0.00	0.00
INITIAL SCALE FACTORS FOR THE DBH INCREMENT MODEL	1.14	1.54	1.00	1.00	1.00	1.00	1.00
NUMBER OF RECORDS AVAILABLE FOR SCALING THE SMALL TREE HEIGHT INCREMENT MODEL	0	0	0	0	0	0	0
INITIAL SCALE FACTORS FOR THE SMALL TREE HEIGHT INCREMENT MODEL	1.00	1.00	1.00	1.00	1.00	1.00	1.00

(con.)

STAND GROWTH PROGNOSIS SYSTEM   VERSION 5.1 -- INLAND EMPIRE

STAND ID: EXAMPLE2   MANAGEMENT CODE: NONE   EVENT MONITOR USER'S GUIDE, EXAMPLE 2

STAND COMPOSITION (BASED ON STOCKABLE AREA)

YEAR	STAND ATTRIBUTES	PERCENTILE POINTS IN THE DISTRIBUTION OF STAND ATTRIBUTES BY DBH (DBH IN INCHES): 10	30	50	70	90	100	TOTAL/ACRE OF STAND ATTRIBUTES	DISTRIBUTION OF STAND ATTRIBUTES BY SPECIES AND 3 USER-DEFINED SUBCLASSES			
1972	TREES	0.1	0.1	2.3	7.7	16.6	32.8	371. TREES	22.% AF2,	20.% GF2,	14.% WP2,	12.% L1
	VOLUME:											
	TOTAL	10.1	17.6	21.8	25.8	29.5	32.8	6229. CUFT	39.% DF1,	18.% WP2,	13.% DF2,	7.% LP2
	MERCH	11.3	18.8	21.9	25.8	29.5	32.8	5841. CUFT	40.% DF1,	19.% WP2,	14.% DF2,	7.% LP2
	MERCH	12.4	18.8	22.1	26.0	29.5	32.8	30364. BDFT	42.% DF1,	18.% WP2,	15.% DF2,	6.% LP2
	ACCRETION	7.7	10.5	17.6	21.9	27.5	32.8	97. CUFT/YR	32.% DF1,	18.% WP2,	9.% AF2,	7.% GF2
	MORTALITY	7.7	14.2	19.0	22.7	27.5	32.8	28. CUFT/YR	30.% DF1,	17.% WP2,	14.% LP2,	14.% DF2
1982	TREES	0.1	1.9	7.1	11.0	19.7	33.9	280. TREES	20.% AF2,	19.% GF2,	13.% L1,	12.% WP2
	VOLUME:											
	TOTAL	11.1	17.9	22.3	26.0	30.4	33.9	6918. CUFT	38.% DF1,	18.% WP2,	12.% DF2,	6.% GF2
	MERCH	11.2	18.0	22.6	26.3	30.4	33.9	6619. CUFT	39.% DF1,	18.% WP2,	13.% DF2,	6.% GF2
	MERCH	12.2	19.6	22.8	26.3	30.4	33.9	34384. BDFT	41.% DF1,	18.% WP2,	14.% DF2,	6.% GF2
	ACCRETION	9.0	12.2	17.1	22.7	28.3	33.9	98. CUFT/YR	30.% DF1,	17.% WP2,	9.% AF2,	8.% GF1
	MORTALITY	8.4	12.8	19.3	23.4	29.7	33.9	35. CUFT/YR	30.% DF1,	17.% WP2,	14.% LP2,	12.% L1
1992	TREES	0.1	2.3	8.9	12.9	22.2	34.8	218. TREES	17.% AF2,	16.% GF2,	14.% L1,	13.% DF1
	VOLUME:											
	TOTAL	12.0	18.1	23.1	26.5	31.2	34.8	7552. CUFT	37.% DF1,	18.% WP2,	12.% DF2,	6.% GF2
	MERCH	12.2	18.3	23.1	26.5	31.2	34.8	7271. CUFT	38.% DF1,	18.% WP2,	12.% DF2,	6.% GF2
	MERCH	12.9	18.8	23.5	26.8	31.4	34.8	38004. BDFT	40.% DF1,	18.% WP2,	13.% DF2,	6.% GF2
	ACCRETION	10.6	13.3	17.7	23.5	28.5	34.8	93. CUFT/YR	30.% DF1,	15.% WP2,	11.% AF2,	10.% GF1
	MORTALITY	9.3	13.7	20.2	24.4	30.6	34.8	43. CUFT/YR	30.% DF1,	17.% WP2,	12.% LP2,	11.% L1
2002	TREES	0.9	7.8	11.6	14.8	23.9	35.4	177. TREES	16.% AF2,	15.% DF1,	14.% GF2,	14.% L1
	VOLUME:											
	TOTAL	13.0	18.6	23.4	27.1	31.9	35.4	8053. CUFT	37.% DF1,	18.% WP2,	11.% DF2,	7.% GF2
	MERCH	13.3	18.7	23.5	27.3	31.9	35.4	7798. CUFT	37.% DF1,	18.% WP2,	11.% DF2,	7.% GF2
	MERCH	13.4	18.9	23.9	27.4	31.9	35.4	41171. BDFT	39.% DF1,	17.% WP2,	12.% DF2,	6.% GF2
	ACCRETION	10.0	13.4	16.7	23.2	29.4	35.4	95. CUFT/YR	27.% DF1,	13.% GF1,	12.% WP2,	11.% S2
	MORTALITY	9.5	14.5	21.2	25.5	31.6	35.4	50. CUFT/YR	30.% DF1,	20.% WP2,	10.% LP2,	10.% DF2

(con.)

Example 2. (Con.)

2012	TREES	2.3	9.3	13.6	16.3	25.0	35.7	150.	TREES	17.% DF1,	15.% AF2,	13.% L1,	13.% GF2
	VOLUME:												
	TOTAL	13.8	18.8	24.1	27.6	32.8	35.7	8504.	CUFT	36.% DF1,	17.% WP2,	10.% DF2,	7.% GF2
	MERCH	14.0	19.1	24.1	27.7	33.0	35.7	8255.	CUFT	37.% DF1,	17.% WP2,	11.% DF2,	7.% GF2
	MERCH	14.6	19.3	24.2	28.0	33.0	35.7	44133.	BDFT	38.% DF1,	16.% WP2,	11.% DF2,	7.% GF2
	ACCRETION	12.8	15.4	18.2	24.1	30.1	35.7	96.	CUFT/YR	26.% DF1,	14.% GF1,	13.% WP2,	12.% AF2
	MORTALITY	10.8	15.9	21.9	26.0	32.0	35.7	55.	CUFT/YR	30.% DF1,	20.% WP2,	9.% DF2,	9.% L1
2022	TREES	3.4	10.8	14.7	18.9	26.3	36.2	129.	TREES	18.% DF1,	15.% AF2,	13.% S2,	12.% L1
	VOLUME:												
	TOTAL	14.5	19.2	24.3	28.1	33.5	36.2	8912.	CUFT	36.% DF1,	16.% WP2,	10.% DF2,	7.% GF2
	MERCH	14.6	19.2	24.3	28.2	33.8	36.2	8665.	CUFT	36.% DF1,	16.% WP2,	10.% DF2,	7.% GF2
	MERCH	15.0	19.4	24.6	28.3	33.8	36.2	46789.	BDFT	37.% DF1,	15.% WP2,	10.% DF2,	7.% S2
	REMOVAL	3.4	10.8	14.7	18.9	26.3	36.2	129.	TREES	18.% DF1,	15.% AF2,	13.% S2,	12.% L1
	VOLUME:												
	TOTAL	14.5	19.2	24.3	28.1	33.5	36.2	8912.	CUFT	36.% DF1,	16.% WP2,	10.% DF2,	7.% GF2
	MERCH	14.6	19.2	24.3	28.2	33.8	36.2	8665.	CUFT	36.% DF1,	16.% WP2,	10.% DF2,	7.% GF2
	MERCH	15.0	19.4	24.6	28.3	33.8	36.2	46789.	BDFT	37.% DF1,	15.% WP2,	10.% DF2,	7.% S2
	RESIDUAL	7.5	7.5	7.5	7.5	7.5	7.5	0.	TREES	100.% L1,	0.% ---,	0.% ---,	0.% ---
	ACCRETION	7.5	7.5	7.5	7.5	7.5	7.5	0.	CUFT/YR	100.% L1,	0.% ---,	0.% ---,	0.% ---
	MORTALITY	7.5	7.5	7.5	7.5	7.5	7.5	0.	CUFT/YR	100.% L1,	0.% ---,	0.% ---,	0.% ---
2032	TREES	0.3	0.4	0.4	0.4	0.4	8.9	540.	TREES	50.% L1,	50.% S1,	0.% ---,	0.% ---
	VOLUME:												
	TOTAL	8.1	8.1	8.9	8.9	8.9	8.9	0.	CUFT	100.% L1,	0.% ---,	0.% ---,	0.% ---
	MERCH	8.1	8.1	8.9	8.9	8.9	8.9	0.	CUFT	100.% L1,	0.% ---,	0.% ---,	0.% ---
	MERCH	8.1	8.1	8.9	8.9	8.9	8.9	0.	BDFT	100.% L1,	0.% ---,	0.% ---,	0.% ---
	ACCRETION	0.3	0.4	0.4	0.4	0.4	8.9	3.	CUFT/YR	51.% S1,	49.% L1,	0.% ---,	0.% ---
	MORTALITY	8.1	8.1	8.1	8.1	8.9	8.9	0.	CUFT/YR	100.% L1,	0.% ---,	0.% ---,	0.% ---
2042	TREES	0.9	1.1	1.4	1.6	2.1	9.6	424.	TREES	56.% S1,	44.% L1,	0.% ---,	0.% ---
	VOLUME:												
	TOTAL	1.1	1.4	1.7	2.1	2.3	9.6	34.	CUFT	51.% S1,	49.% L1,	0.% ---,	0.% ---
	MERCH	9.2	9.2	9.6	9.6	9.6	9.6	0.	CUFT	100.% L1,	0.% ---,	0.% ---,	0.% ---
	MERCH	9.2	9.2	9.6	9.6	9.6	9.6	0.	BDFT	100.% L1,	0.% ---,	0.% ---,	0.% ---
	ACCRETION	1.2	1.4	1.7	2.1	2.3	9.6	21.	CUFT/YR	57.% L1,	43.% S1,	0.% ---,	0.% ---
	MORTALITY	0.9	1.2	1.4	1.7	2.1	9.6	0.	CUFT/YR	54.% L1,	46.% S1,	0.% ---,	0.% ---

(con.)

2052	TREES	1.9	2.6	3.3	3.9	4.7	10.5	387.	TREES	56.% S1,	44.% L1,	0.% ---,	0.% ---
	VOLUME:												
	TOTAL	2.8	3.7	4.0	4.5	5.3	10.5	245.	CUFT	56.% L1,	44.% S1,	0.% ---,	0.% ---
	MERCH	10.1	10.1	10.5	10.5	10.5	10.5	0.	CUFT	100.% L1,	0.% ---,	0.% ---,	0.% ---
	MERCH	10.1	10.1	10.5	10.5	10.5	10.5	0.	BDFT	100.% L1,	0.% ---,	0.% ---,	0.% ---
	ACCRETION	2.5	3.2	3.8	4.2	5.1	10.5	54.	CUFT/YR	53.% S1,	47.% L1,	0.% ---,	0.% ---
	MORTALITY	2.1	2.9	3.6	4.0	4.5	10.5	1.	CUFT/YR	65.% L1,	35.% S1,	0.% ---,	0.% ---
2062	TREES	3.6	4.8	5.4	6.0	7.4	13.4	373.	TREES	57.% S1,	43.% L1,	0.% ---,	0.% ---
	VOLUME:												
	TOTAL	4.7	5.5	6.0	6.9	7.5	13.4	778.	CUFT	50.% S1,	50.% L1,	0.% ---,	0.% ---
	MERCH	7.2	7.4	7.5	7.7	8.0	13.4	169.	CUFT	66.% S1,	34.% L1,	0.% ---,	0.% ---
	MERCH	7.2	7.4	7.5	7.7	8.0	13.4	614.	BDFT	63.% S1,	37.% L1,	0.% ---,	0.% ---
	ACCRETION	4.3	5.3	5.8	6.9	7.9	13.4	93.	CUFT/YR	63.% S1,	37.% L1,	0.% ---,	0.% ---
	MORTALITY	4.2	4.9	5.8	6.2	7.4	13.4	2.	CUFT/YR	68.% L1,	32.% S1,	0.% ---,	0.% ---
2072	TREES	5.4	6.5	7.2	8.3	9.3	15.0	358.	TREES	58.% S1,	42.% L1,	0.% ---,	0.% ---
	VOLUME:												
	TOTAL	6.3	7.2	8.2	9.1	10.1	15.0	1686.	CUFT	57.% S1,	43.% L1,	0.% ---,	0.% ---
	MERCH	7.3	8.1	8.9	9.2	10.6	15.0	1071.	CUFT	60.% S1,	40.% L1,	0.% ---,	0.% ---
	MERCH	7.4	8.2	9.0	9.2	11.3	15.0	4400.	BDFT	61.% S1,	39.% L1,	0.% ---,	0.% ---
	ACCRETION	6.4	7.3	8.3	9.2	10.6	15.0	128.	CUFT/YR	73.% S1,	27.% L1,	0.% ---,	0.% ---
	MORTALITY	5.8	6.7	7.7	8.8	9.8	15.0	9.	CUFT/YR	56.% L1,	44.% S1,	0.% ---,	0.% ---
2082	TREES	6.5	7.7	8.9	10.0	12.2	16.7	336.	TREES	59.% S1,	41.% L1,	0.% ---,	0.% ---
	VOLUME:												
	TOTAL	7.5	8.9	10.0	11.7	13.9	16.7	2879.	CUFT	65.% S1,	35.% L1,	0.% ---,	0.% ---
	MERCH	8.0	9.5	10.5	11.7	13.9	16.7	2422.	CUFT	66.% S1,	34.% L1,	0.% ---,	0.% ---
	MERCH	8.2	9.5	10.9	12.2	15.6	16.7	11338.	BDFT	69.% S1,	31.% L1,	0.% ---,	0.% ---
	REMOVAL	5.5	6.7	7.3	7.6	8.0	8.3	128.	TREES	57.% L1,	43.% S1,	0.% ---,	0.% ---
	VOLUME:												
	TOTAL	6.0	7.1	7.4	7.7	8.2	8.3	551.	CUFT	62.% L1,	38.% S1,	0.% ---,	0.% ---
	MERCH	7.3	7.4	7.6	8.0	8.3	8.3	325.	CUFT	68.% L1,	32.% S1,	0.% ---,	0.% ---
	MERCH	7.3	7.4	7.6	8.0	8.3	8.3	1259.	BDFT	70.% L1,	30.% S1,	0.% ---,	0.% ---
	RESIDUAL	8.6	9.4	9.9	11.4	13.3	16.7	208.	TREES	68.% S1,	32.% L1,	0.% ---,	0.% ---
	ACCRETION	8.7	9.7	11.4	12.2	13.9	16.7	114.	CUFT/YR	83.% S1,	17.% L1,	0.% ---,	0.% ---
	MORTALITY	8.7	9.5	10.0	11.6	13.9	16.7	11.	CUFT/YR	57.% S1,	43.% L1,	0.% ---,	0.% ---

(con.)

Example 2. (Con.)

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2092  TREES          9.8   10.5   11.3   13.2   15.8   19.2     198. TREES      69.% S1,  31.% L1,  0.% ---,  0.% ---
      VOLUME:
        TOTAL       10.2   11.2   13.1   14.4   18.5   19.2    3358. CUFT       76.% S1,  24.% L1,  0.% ---,  0.% ---
        MERCH       10.2   11.2   13.1   14.4   18.5   19.2    3101. CUFT       76.% S1,  24.% L1,  0.% ---,  0.% ---
        MERCH       10.3   11.6   13.3   14.6   18.5   19.2   16558. BDFT       80.% S1,  20.% L1,  0.% ---,  0.% ---

      ACCRETION     10.2   11.2   13.1   14.2   17.8   19.2     136. CUFT/YR    86.% S1,  14.% L1,  0.% ---,  0.% ---
      MORTALITY      9.9   10.6   11.5   13.5   17.8   19.2      25. CUFT/YR    60.% S1,  40.% L1,  0.% ---,  0.% ---


2102  TREES         11.0   11.8   13.4   14.9   19.1   21.5     182. TREES      71.% S1,  29.% L1,  0.% ---,  0.% ---
      VOLUME:
        TOTAL       11.1   13.2   14.6   16.8   20.7   21.5    4469. CUFT       80.% S1,  20.% L1,  0.% ---,  0.% ---
        MERCH       11.1   13.2   14.8   16.8   20.7   21.5    4192. CUFT       80.% S1,  20.% L1,  0.% ---,  0.% ---
        MERCH       11.5   13.5   15.5   17.2   21.0   21.5   24100. BDFT       85.% S1,  15.% L1,  0.% ---,  0.% ---

      ACCRETION     11.7   14.1   14.9   16.8   21.0   21.5     143. CUFT/YR    89.% S1,  11.% L1,  0.% ---,  0.% ---
      MORTALITY     10.9   12.0   14.2   16.0   20.7   21.5      36. CUFT/YR    68.% S1,  32.% L1,  0.% ---,  0.% ---


2112  TREES         11.4   12.8   15.5   17.2   20.4   25.0     166. TREES      72.% S1,  28.% L1,  0.% ---,  0.% ---
      VOLUME:
        TOTAL       12.3   14.9   17.1   18.9   23.8   25.0    5537. CUFT       83.% S1,  17.% L1,  0.% ---,  0.% ---
        MERCH       12.4   14.9   17.1   18.9   23.8   25.0    5243. CUFT       83.% S1,  17.% L1,  0.% ---,  0.% ---
        MERCH       12.4   15.6   17.2   19.0   23.8   25.0   31222. BDFT       87.% S1,  13.% L1,  0.% ---,  0.% ---

      REMOVAL       11.3   12.3   13.3   14.3   16.2   16.9     102. TREES      55.% S1,  45.% L1,  0.% ---,  0.% ---
      VOLUME:
        TOTAL       11.3   12.4   13.5   14.9   16.6   16.9    2365. CUFT       61.% S1,  39.% L1,  0.% ---,  0.% ---
        MERCH       11.4   12.4   13.5   14.9   16.6   16.9    2221. CUFT       61.% S1,  39.% L1,  0.% ---,  0.% ---
        MERCH       11.7   12.6   13.7   15.5   16.6   16.9   11871. BDFT       67.% S1,  33.% L1,  0.% ---,  0.% ---

      RESIDUAL      17.0   17.2   17.8   19.0   23.8   25.0      64. TREES      99.% S1,   1.% L1,  0.% ---,  0.% ---

      ACCRETION     17.1   17.3   18.9   21.7   23.8   25.0      76. CUFT/YR   100.% S1,   0.% L1,  0.% ---,  0.% ---
      MORTALITY     17.0   17.3   18.9   21.7   23.8   25.0       8. CUFT/YR    97.% S1,   3.% L1,  0.% ---,  0.% ---


2122  TREES         17.9   18.6   19.6   20.5   26.3   26.3      63. TREES      99.% S1,   1.% L1,  0.% ---,  0.% ---
      VOLUME:
        TOTAL       18.6   19.0   20.5   23.2   26.3   26.3    3857. CUFT       99.% S1,   1.% L1,  0.% ---,  0.% ---
        MERCH       18.6   19.0   20.5   23.2   26.3   26.3    3691. CUFT       99.% S1,   1.% L1,  0.% ---,  0.% ---
        MERCH       18.6   19.6   20.5   23.2   26.3   26.3   23940. BDFT      100.% S1,   0.% L1,  0.% ---,  0.% ---
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(con.)

STAND ID; EXAMPLE2 MANAGEMENT CODE: NONE EVENT MONITOR USER'S GUIDE, EXAMPLE 2

	ATTRIBUTES OF SELECTED SAMPLE TREES								ADDITIONAL STAND ATTRIBUTES (BASED ON STOCKABLE AREA)					
YEAR	INITIAL TREES/A %TILE	SPECIES	DBH (INCHES)	HEIGHT (FEET)	LIVE CROWN RATIO	PAST DBH GROWTH (INCHES)	BASAL AREA %TILE	TREES PER ACRE	STAND AGE	QUADRATIC MEAN DBH (INCHES)	TREES PER ACRE	BASAL AREA (SQFT/A)	TOP HEIGHT LARGEST 40/A (FT)	CROWN COMP FACTOR
1972						(10 YRS)								
	10	AF2	0.10	1.00	45	0.00	0.0	33.33						
	30	GF2	0.10	1.00	35	0.00	0.0	33.33						
	50	GF2	2.30	8.00	35	0.53	0.9	33.33						
	70	WP2	7.70	52.00	15	1.20	11.6	13.74						
	90	L1	16.60	105.00	25	0.60	41.1	2.96						
	100	DF2	32.80	149.00	35	0.90	100.0	0.76						
									150	9.1	371.	166.	114.6	146.0
1982						(10 YRS)								
	10	AF2	0.10	3.05	45	0.00	0.0	18.16						
	30	GF2	0.10	2.93	35	0.00	0.0	19.60						
	50	GF2	2.30	10.68	35	0.00	0.6	25.07						
	70	WP2	8.35	59.04	14	0.63	10.2	13.12						
	90	L1	17.08	108.14	24	0.41	39.5	2.77						
	100	DF2	33.27	150.83	35	0.41	99.4	0.74						
									160	10.8	280.	179.	116.7	153.8
1992						(10 YRS)								
	10	AF2	0.10	4.29	45	0.00	0.0	9.75						
	30	GF2	0.10	4.03	35	0.00	0.0	11.38						
	50	GF2	2.30	14.11	35	0.00	0.4	16.74						
	70	WP2	8.93	65.80	13	0.55	7.2	11.59						
	90	L1	17.53	111.12	23	0.38	39.2	2.47						
	100	DF2	33.72	152.58	35	0.39	98.9	0.71						
									170	12.7	218.	190.	119.3	160.4
2002						(10 YRS)								
	10	AF2	0.73	5.67	45	0.59	0.0	5.18						
	30	GF2	0.86	6.28	35	0.70	0.0	6.54						
	50	GF2	2.47	17.69	35	0.15	0.2	11.02						
	70	WP2	9.25	69.50	12	0.31	5.8	10.00						
	90	L1	18.17	114.80	23	0.55	39.0	2.17						
	100	DF2	34.16	154.29	35	0.38	99.0	0.68						
									180	14.3	177.	197.	122.5	164.0
2012						(10 YRS)								
	10	AF2	0.92	7.26	45	0.17	0.0	3.33						
	30	GF2	1.29	9.49	35	0.39	0.0	4.87						
	50	GF2	2.96	20.98	35	0.45	0.2	7.16						
	70	WP2	9.68	73.99	12	0.41	5.0	7.97						
	90	L1	18.63	117.69	23	0.39	39.7	1.96						
	100	DF2	34.54	155.85	35	0.33	98.7	0.64						
									190	15.8	150.	203.	124.8	166.8

(con.)

Example 2. (Con.)

2022						(10 YRS)								
	10	AF2	1.14	8.76	45	0.21	0.0	2.01						
	30	GF2	1.61	11.72	35	0.29	0.0	3.19						
	50	GF2	3.70	25.89	40	0.68	0.2	5.12						
	70	WP2	10.18	78.96	12	0.48	4.1	6.56						
	90	L1	18.96	120.02	22	0.28	37.1	1.70						
	100	DF2	34.88	157.31	35	0.30	98.7	0.61						
									0	17.2	129.	208.	126.4	168.1
									RESIDUAL:	7.5	0.	0.	58.3	0.0
2032 **						(10 YRS)								
	10	L1	0.27	7.69	65	0.00	5.4	5.56						
	30	S1	0.40	4.86	54	0.00	22.5	5.56						
	50	S1	0.40	2.52	86	0.00	44.4	6.11						
	70	L1	0.40	4.71	56	0.00	67.3	6.11						
	90	S1	0.40	1.62	66	0.00	89.4	5.56						
	100	L1	8.92	70.93	58	1.24	100.0	0.00						
									10	0.4	540.	0.	2.7	0.7
2042 **						(10 YRS)								
	10	L1	0.92	6.30	78	0.44	2.9	3.92						
	30	L1	1.13	8.54	76	0.62	12.3	3.92						
	50	S1	1.38	9.43	75	0.93	27.3	4.85						
	70	S1	1.64	10.95	74	1.19	47.1	4.85						
	90	L1	2.11	18.76	55	1.57	78.4	3.80						
	100	L1	9.56	79.45	56	0.54	100.0	0.00						
									20	1.5	424.	5.	19.5	6.5
2052						(10 YRS)								
	10	L1	1.44	10.77	78	0.44	0.5	2.80						
	30	L1	2.07	14.60	76	0.80	4.2	3.09						
	50	S1	3.84	19.19	87	2.36	45.0	4.62						
	70	S1	3.67	18.04	58	1.94	36.2	4.71						
	90	L1	4.41	30.46	41	1.96	70.0	3.68						
	100	L1	10.51	86.63	55	0.81	100.0	0.00						
									30	3.5	387.	26.	32.8	26.4
2062						(10 YRS)								
	10	L1	2.61	18.64	78	1.00	0.7	1.89						
	30	L1	3.19	21.45	50	0.95	1.2	2.56						
	50	S1	5.80	29.05	84	1.87	44.3	4.58						
	70	S1	5.76	25.64	59	2.00	42.0	4.64						
	90	L1	5.78	39.00	35	1.16	43.0	3.59						
	100	L1	12.45	96.76	55	1.65	100.0	0.00						
									40	5.6	373.	63.	35.9	58.6
2072						(10 YRS)								
	10	L1	3.68	25.98	38	0.91	0.3	1.62						
	30	L1	3.79	30.34	44	0.52	0.5	2.20						
	50	S1	7.34	34.88	83	1.47	35.5	4.49						
	70	S1	9.20	37.33	62	3.29	76.8	4.56						
	90	L1	6.33	48.79	25	0.47	12.3	3.42						
	100	L1	13.97	104.57	55	1.29	100.0	0.00						
									50	7.6	358.	113.	39.0	97.7

(con.)

2082						(10 YRS)								
	10	L1	4.37	30.67	36	0.58	0.2	1.34						
	30	L1	4.27	34.91	40	0.41	0.1	1.56						
	50	S1	8.66	41.08	81	1.26	27.7	4.29						
	70	S1	12.18	48.44	61	2.85	77.9	4.39						
	90	L1	6.67	52.87	20	0.30	4.0	2.87						
	100	L1	14.38	107.59	54	0.35	92.9	0.00						
									60	9.5	336.	164.	49.4	135.5
									RESIDUAL:	10.7	208.	130.	49.4	104.6
2092						(10 YRS)								
	10	L1	5.15	35.31	36	0.67	0.0	0.02						
	30	L1	5.19	39.90	40	0.78	0.0	0.02						
	50	S1	10.46	48.31	80	1.72	17.8	4.09						
	70	S1	13.53	54.04	60	1.29	64.2	4.22						
	90	L1	7.37	59.77	20	0.59	0.1	0.04						
	100	L1	15.64	113.92	54	1.08	78.5	0.00						
									70	12.5	198.	167.	56.4	129.2
2102						(10 YRS)								
	10	L1	5.49	39.46	35	0.29	0.0	0.02						
	30	L1	5.68	44.34	39	0.42	0.0	0.02						
	50	S1	11.67	53.96	76	1.16	16.3	3.86						
	70	S1	14.24	57.51	54	0.68	44.5	3.97						
	90	L1	8.03	64.11	19	0.57	0.1	0.04						
	100	L1	16.31	117.80	52	0.56	69.0	0.00						
									80	14.3	182.	202.	64.5	148.3
2112						(10 YRS)								
	10	L1	6.24	44.50	35	0.64	0.0	0.01						
	30	L1	5.82	46.24	38	0.12	0.0	0.01						
	50	S1	12.35	57.58	72	0.65	11.1	3.57						
	70	S1	15.49	62.47	50	1.19	33.5	3.65						
	90	L1	8.38	67.91	18	0.30	0.0	0.03						
	100	L1	17.76	124.25	50	1.24	65.0	0.00						
									90	16.0	166.	231.	70.5	162.4
									RESIDUAL:	19.3	64.	130.	70.5	84.9
2122						(10 YRS)								
	10	L1	6.78	48.50	35	0.46	0.0	0.00						
	30	L1	6.43	52.84	38	0.52	0.0	0.00						
	50	S1	13.21	61.72	77	0.82	0.3	0.07						
	70	S1	16.61	66.89	56	1.07	1.1	0.07						
	90	L1	9.72	76.72	18	1.14	0.0	0.00						
	100	L1	19.20	130.28	53	1.23	32.7	0.00						
									100	20.9	63.	149.	76.4	94.9

** NOTE: DUE TO HARVEST, COMPRESSION, OR REGENERATION ESTABLISHMENT, NEW SAMPLE TREES WERE SELECTED.

(con.)

Example 2. (Con.)

			VOLUME PER ACRE			REMOVALS PER ACRE							GROWTH				IDENTIFIERS	
YEAR	AGE	TREES /ACRE	TOTAL CU FT	MERCH CU FT	MERCH BD FT	TREES /ACRE	TOTAL CU FT	MERCH CU FT	MERCH BD FT	BA/ ACRE SQFT	CCF	TOP HT FT	PRD YRS	ACC CUFT/YR	MOR CUFT/YR	STAND SAMPLE WEIGHT	STAND	MGMT
1972	150	371	6229	5841	30364	0	0	0	0	166	146	115	10	97	28	9	EXAMPLE2	NONE
1982	160	280	6918	6619	34384	0	0	0	0	179	154	117	10	98	35	9	EXAMPLE2	NONE
1992	170	218	7552	7271	38004	0	0	0	0	190	160	119	10	93	43	9	EXAMPLE2	NONE
2002	180	177	8053	7798	41171	0	0	0	0	197	164	122	10	95	50	9	EXAMPLE2	NONE
2012	190	150	8504	8255	44133	0	0	0	0	203	167	125	10	96	55	9	EXAMPLE2	NONE
2022	0	129	8912	8665	46789	129	8912	8665	46789	0	0	58	10	0	0	9	EXAMPLE2	NONE
2032	10	540	0	0	0	0	0	0	0	0	1	3	10	3	0	9	EXAMPLE2	NONE
2042	20	424	34	0	0	0	0	0	0	5	6	19	10	21	0	9	EXAMPLE2	NONE
2052	30	387	245	0	0	0	0	0	0	26	26	33	10	54	1	9	EXAMPLE2	NONE
2062	40	373	778	169	614	0	0	0	0	63	59	36	10	93	2	9	EXAMPLE2	NONE
2072	50	358	1686	1071	4400	0	0	0	0	113	98	39	10	128	9	9	EXAMPLE2	NONE
2082	60	336	2879	2422	11338	128	551	325	1259	130	105	49	10	114	11	9	EXAMPLE2	NONE
2092	70	198	3358	3101	16558	0	0	0	0	167	129	56	10	136	25	9	EXAMPLE2	NONE
2102	80	182	4469	4192	24100	0	0	0	0	202	148	65	10	143	36	9	EXAMPLE2	NONE
2112	90	166	5537	5243	31222	102	2365	2221	11871	130	85	71	10	76	8	9	EXAMPLE2	NONE
2122	100	63	3857	3691	23940	0	0	0	0	149	95	76	0	0	0	9	EXAMPLE2	NONE

ACTIVITY SUMMARY

STAND ID= EXAMPLE2 MANAGEMENT ID= NONE EVENT MONITOR USER'S GUIDE, EXAMPLE 2

CYCLE	DATE	EXTENSION	KEYWORD	DATE	ACTIVITY DISPOSITION	PARAMETERS:			
1	1972								
2	1982								
3	1992								
4	2002								
5	2012								
6	2022								
		BASE	THINATA	2022	DONE IN 2022	0.00	1.00	0.00	999.00
		ESTB	BURNPREP	2023	DONE IN 2023	80.00			
		ESTB	MECHPREP	2023	DONE IN 2023	20.00			
		ESTB	PLANT	2024	DONE IN 2024	2.00	300.00	90.00	
		ESTB	PLANT	2024	DONE IN 2024	8.00	300.00	90.00	
		ESTB	STOCKADJ	2031	DONE IN 2031	-1.00			
		ESTB	RESETAGE	2022	DONE IN 2031	0.00			
		ESTB	TALLYONE	2031	DONE IN 2031	2022.00			
7	2032								
		ESTB	TALLYTWO	2041	DONE IN 2041	2022.00			
8	2042								
9	2052								
10	2062								
11	2072								
12	2082								
		BASE	THINBBA	2082	DONE IN 2082	130.00	0.98	0.00	999.00
13	2092								
14	2102								
15	2112								
		BASE	THINBBA	2112	DONE IN 2112	130.00	0.98	0.00	999.00

(con.)

```
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *
*                                                                     *
*           REGENERATION ESTABLISHMENT MODEL VERSION 1.0              *
*                                                                     *
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *

THE PRESCRIPTION FOR STAND: EXAMPLE2    MANAGEMENT ID: NONE

    DATE OF    SITE PREP, DATE, AND PERCENT    NUMBER OF PLOTS
    DISTURB-   ----------------------------    BY HABITAT TYPE
    ANCE       NONE PCT  MECH PCT  BURN PCT    520 530 570 620
    --------   ---- ---  ---- ---  ---- ---    --- --- --- ---
        2022   2022   0  2023  20  2023  80      0   0   0   9

CUMULATIVE PROBABILITY OF STOCKING IS 0.0000 IN THE FALL OF 2031
NOTE: REPORTED PROBABILITY OF STOCKING DOES NOT INCLUDE PLANTED TREES.
SPECIES PLANTED: L   S

                ADDITIONAL    SUBSAMPLE OF "BEST"   REGENERATION(<3"DBH)
                REGENERATION  TREES REGENERATING    BEING PROJECTED BY
  TALLYONE      THIS TALLY.   DURING THIS TALLY.    THE PROGNOSIS MODEL.
                -----------   ------------------    --------------------
                TREES % OF    TREES % OF  AVERAGE   TREES  % OF
        SPECIES /ACRE TOTAL   /ACRE TOTAL HEIGHT    /ACRE  TOTAL SPECIES
        ------- ----- -----   ----- ----- -------   -----  ----- -------
           WP      0.    0.      0.    0.   0.0        0.     0.  WP
           L     270.   50.    270.   50.   5.5      270.    50.  L
           DF      0.    0.      0.    0.   0.0        0.     0.  DF
           GF      0.    0.      0.    0.   0.0        0.     0.  GF
           WH      0.    0.      0.    0.   0.0        0.     0.  WH
           C       0.    0.      0.    0.   0.0        0.     0.  C
           LP      0.    0.      0.    0.   0.0        0.     0.  LP
           S     270.   50.    270.   50.   3.2      270.    50.  S
           AF      0.    0.      0.    0.   0.0        0.     0.  AF
           PP      0.    0.      0.    0.   0.0        0.     0.  PP
                -----         -----                 -----
                 540.          540.                  540.

CUMULATIVE PROBABILITY OF STOCKING IS 0.0000 IN THE FALL OF 2041

                ADDITIONAL    SUBSAMPLE OF "BEST"   REGENERATION(<3"DBH)
                REGENERATION  TREES REGENERATING    BEING PROJECTED BY
  TALLYTWO      THIS TALLY.   DURING THIS TALLY.    THE PROGNOSIS MODEL.
                -----------   ------------------    --------------------
                TREES % OF    TREES % OF  AVERAGE   TREES  % OF
        SPECIES /ACRE TOTAL   /ACRE TOTAL HEIGHT    /ACRE  TOTAL SPECIES
        ------- ----- -----   ----- ----- -------   -----  ----- -------
           WP      0.    0.      0.    0.   0.0        0.     0.  WP
           L       0.    0.      0.    0.   0.0      188.    44.  L
           DF      0.    0.      0.    0.   0.0        0.     0.  DF
           GF      0.    0.      0.    0.   0.0        0.     0.  GF
           WH      0.    0.      0.    0.   0.0        0.     0.  WH
           C       0.    0.      0.    0.   0.0        0.     0.  C
           LP      0.    0.      0.    0.   0.0        0.     0.  LP
           S       0.    0.      0.    0.   0.0      236.    56.  S
           AF      0.    0.      0.    0.   0.0        0.     0.  AF
           PP      0.    0.      0.    0.   0.0        0.     0.  PP
                -----         -----                 -----
                   0.            0.                  424.
```

Example 3.

```
                     STAND GROWTH PROGNOSIS SYSTEM          VERSION 5.0 -- INLAND EMPIRE (TEST)

                           PARALLEL PROCESSING EXTENSION -- VERSION 1.0
-------------------------------------------------------------------------------------------------

                                   OPTIONS SELECTED BY INPUT

-------------------------------------------------------------------------------------------------
KEYWORD    PARAMETERS:
--------   --------------------------------------------------------------------------------------

ADDSTAND   ADD ONE STAND TO THE DATA BASE.

STDIDENT
           STAND ID= EXAMPLE3           EVENT MONITOR USER'S GUIDE EXAMPLE 3.

INVYEAR    INVENTORY YEAR= 1972

NUMCYCLE   NUMBER OF CYCLES= 10

IF         MINIMUM DELAY TIME BETWEEN RESPONSES TO THE EVENT =   999

             BCCF GT 150 AND BTPA GT 500 AND AGE &
             GT 20 AND AGE LT 60

THEN       ACTIVITIES WHICH FOLLOW WILL NOT BE SCHEDULED UNTIL THE EVENT HAPPENS (WHEN THE LOGICAL EXPRESSION IS TRUE).

THINBTA    DATE/CYCLE=    0; RESIDUAL=  300.00; PROPORTION OF SELECTED TREES REMOVED= 0.980
           DBH OF REMOVED TREES WILL RANGE FROM   0.0 TO 999.0 INCHES

ALSOTRY    ACTIVITIES WHICH FOLLOW WILL NOT BE SCHEDULED UNTIL THE EVENT HAPPENS (WHEN THE LOGICAL EXPRESSION IS TRUE).

THINBTA    DATE/CYCLE=    0; RESIDUAL=  400.00; PROPORTION OF SELECTED TREES REMOVED= 0.980
           DBH OF REMOVED TREES WILL RANGE FROM   0.0 TO 999.0 INCHES

ALSOTRY    ACTIVITIES WHICH FOLLOW WILL NOT BE SCHEDULED UNTIL THE EVENT HAPPENS (WHEN THE LOGICAL EXPRESSION IS TRUE).

ENDIF      ACTIVITIES WHICH FOLLOW WILL BE SCHEDULED.

STDINFO    FOREST CODE= 18; HABITAT TYPE=710; AGE=   10; ASPECT CODE=  4.; SLOPE CODE=  5.
           ELEVATION(100'S FEET)= 56.0; SITE INDEX=   0.

PROCESS    PROCESS THE STAND.

-------------------------------------------------------------------------------------------------

                                   OPTIONS SELECTED BY DEFAULT

-------------------------------------------------------------------------------------------------

TREEFMT    (23X,I4,3X, F2.0,I1, A3,F3.1,F2.1,3X,F3.0,T63,F3.0   ,T60,F3.1,T48,  I1,3X, I2,
           2I1,T66,2I1,I3, 2I1)

DESIGN     BASAL AREA FACTOR= 40.0; INVERSE OF FIXED PLOT AREA=  300.0; BREAK DBH=    5.0
           NUMBER OF PLOTS=    18; NON-STOCKABLE PLOTS=     7; STAND SAMPLING WEIGHT=  18.00000
           STAND ATTRIBUTES ARE CALCULATED PER ACRE OF STOCKABLE AREA.  STAND STATISTICS
           IN SUMMARY TABLE ARE MULTIPLIED BY 0.611 TO INCLUDE TOTAL STAND AREA.
-------------------------------------------------------------------------------------------------
```

(con.)

```
                                          ACTIVITY SCHEDULE

STAND ID= EXAMPLE3    MANAGEMENT ID= NONE        EVENT MONITOR USER'S GUIDE EXAMPLE 3.

----------------------------------------------------------------------------------------------------

CYCLE  DATE  EXTENSION  KEYWORD   DATE  PARAMETERS:
-----  ----  ---------  --------  ----  ---------------------------------------------------------

   1   1972
   2   1982
   3   1992
   4   2002
   5   2012
   6   2022
   7   2032
   8   2042
   9   2052
  10   2062
----------------------------------------------------------------------------------------------------

CALIBRATION STATISTICS:

                                                LP    WP    AF    --     S
                                               ----  ----  ----  ----  ----

NUMBER OF RECORDS PER SPECIES                     2     5    19     5     2

NUMBER OF RECORDS CODED AS RECENT MORTALITY       0     0     0     0     0

NUMBER OF RECORDS WITH MISSING HEIGHTS            0     0     1     1     0

NUMBER OF RECORDS WITH BROKEN OR DEAD TOPS        0     0     0     0     0

NUMBER OF RECORDS WITH MISSING CROWN RATIOS       0     0     0     0     0

NUMBER OF RECORDS AVAILABLE FOR SCALING
THE DIAMETER INCREMENT MODEL                      0     0     1     0     1

RATIO OF STANDARD ERRORS
(INPUT DBH GROWTH DATA : MODEL)                1.00  1.00  1.00  1.00  1.00

WEIGHT GIVEN TO THE INPUT GROWTH DATA WHEN
DBH GROWTH MODEL SCALE FACTORS WERE COMPUTED   0.00  0.00  0.00  0.00  0.00

INITIAL SCALE FACTORS FOR THE
DBH INCREMENT MODEL                            1.00  1.00  1.00  1.00  1.00

NUMBER OF RECORDS AVAILABLE FOR SCALING
THE SMALL TREE HEIGHT INCREMENT MODEL             0     0     0     0     0

INITIAL SCALE FACTORS FOR THE SMALL TREE
HEIGHT INCREMENT MODEL                         1.00  1.00  1.00  1.00  1.00
```

(con.)

Example 3. (Con.)

```
SUMMARY UP TO MASTER STARTING YEAR:

                              SUMMARY STATISTICS (BASED ON TOTAL STAND AREA)
-------------------------------------------------------------------------------------------------------
                    VOLUME PER ACRE       REMOVALS PER ACRE                    GROWTH
                  -----------------  -----------------------  BA/       TOP  -----------  STAND    IDENTIFIERS
          TREES  TOTAL MERCH MERCH  TREES TOTAL MERCH MERCH  ACRE      HT   PRD ACC MOR  SAMPLE  -------------
YEAR AGE  /ACRE  CU FT CU FT BD FT  /ACRE CU FT CU FT BD FT  SQFT CCF  FT   YRS CUFT/YR  WEIGHT   STAND    MGMT
---- ---  -----  ----- ----- -----  ----- ----- ----- -----  ---- ---  ---  --- --- ---  ------  -------- ----
1972  10   1171     98    84   475      0     0     0     0     5   5   19    0   0   0       0 EXAMPLE3 NONE


                             STAND GROWTH PROGNOSIS SYSTEM        VERSION 5.0 -- INLAND EMPIRE (TEST)

                                  PARALLEL PROCESSING EXTENSION -- VERSION 1.0
---------------------------------------------------------------------------------------------------------------------

                                           OPTIONS SELECTED BY INPUT

---------------------------------------------------------------------------------------------------------------------
KEYWORD     PARAMETERS:
--------    ---------------------------------------------------------------------------------------------------------

PROJECT     THERE ARE  1 STANDS TO PROJECT.

NOCOMPOS    COMPOSITE YIELD TABLES WILL NOT BE GENERATED.

YIELDS      PROCESS YIELD TABLES.
---------------------------------------------------------------------------------------------------------------------



                             STAND GROWTH PROGNOSIS SYSTEM        VERSION 5.0 -- INLAND EMPIRE (TEST)

NOTE:  PROCESSING STAND NUMBER:   1; STAND ID: EXAMPLE3  MGMT ID: NONE  SAMPLING WEIGHT:   18.00000
BRANCHING: NODE=1, BRCH=1

                              SUMMARY STATISTICS (BASED ON TOTAL STAND AREA)
-------------------------------------------------------------------------------------------------------
                    VOLUME PER ACRE       REMOVALS PER ACRE                    GROWTH
                  -----------------  -----------------------  BA/       TOP  -----------  STAND    IDENTIFIERS
          TREES  TOTAL MERCH MERCH  TREES TOTAL MERCH MERCH  ACRE      HT   PRD ACC MOR  SAMPLE  -------------
YEAR AGE  /ACRE  CU FT CU FT BD FT  /ACRE CU FT CU FT BD FT  SQFT CCF  FT   YRS CUFT/YR  WEIGHT   STAND    MGMT
---- ---  -----  ----- ----- -----  ----- ----- ----- -----  ---- ---  ---  --- --- ---  ------  -------- ----
1972  10   1171     98    84   475      0     0     0     0     5   5   19   10   8   0      18 EXAMPLE3 NONE
1982  20   1011    181   115   669      0     0     0     0    13  17   25   10  22   0      18 EXAMPLE3 NONE
1992  30    856    393   175   967      0     0     0     0    33  45   31   10  34   2      18 EXAMPLE3 NONE
2002  40    747    718   265  1425      0     0     0     0    62  81   36   10  49   6      18 EXAMPLE3 NONE
2012  50    640   1149   465  2433    457   532     0     0    42  45   38   10  46   3      18 EXAMPLE3 NONE
2022  60    155   1048   871  4531      0     0     0     0    69  70   41   10  38   5      18 EXAMPLE3 NONE
2032  70    141   1374  1173  6170      0     0     0     0    83  82   46   10  49  11      18 EXAMPLE3 NONE
2042  80    122   1756  1545  8143      0     0     0     0    99  95   51   10  52  14      18 EXAMPLE3 NONE
2052  90    108   2136  1942 11720      0     0     0     0   111 105   56   10  61  21      18 EXAMPLE3 NONE
2062 100     93   2531  2354 13457      0     0     0     0   122 112   62   10  50  20      18 EXAMPLE3 NONE
2072 110     82   2825  2663 15049      0     0     0     0   128 116   66    0   0   0      18 EXAMPLE3 NONE
```

(con.)

```
                                                   ACTIVITY SUMMARY

STAND ID= EXAMPLE3    MANAGEMENT ID= NONE       EVENT MONITOR USER'S GUIDE EXAMPLE 3.

--------------------------------------------------------------------------------------------------------------

CYCLE  DATE  EXTENSION  KEYWORD   DATE  ACTIVITY DISPOSITION  PARAMETERS:
-----  ----  ---------  --------  ----  --------------------  ----------------------------------------------

   1   1972
   2   1982
   3   1992
   4   2002

   5   2012
              BASE      THINBTA   2012  DONE IN 2012               300.00      0.98      0.00    999.00

   6   2022
   7   2032
   8   2042
   9   2052
  10   2062
--------------------------------------------------------------------------------------------------------------


                                STAND GROWTH PROGNOSIS SYSTEM        VERSION 5.0 -- INLAND EMPIRE (TEST)

NOTE:  PROCESSING STAND NUMBER:   1; STAND ID: EXAMPLE3  MGMT ID: NONE  SAMPLING WEIGHT:   18.00000
BRANCHING: NODE=1, BRCH=2


                             SUMMARY STATISTICS (BASED ON TOTAL STAND AREA)
----------------------------------------------------------------------------------------------------
                   VOLUME PER ACRE    REMOVALS PER ACRE                      GROWTH
                 ----------------- -----------------------  BA/      TOP  ----------- STAND   IDENTIFIERS
           TREES TOTAL MERCH MERCH TREES TOTAL MERCH MERCH ACRE      HT   PRD ACC MOR SAMPLE -------------
YEAR AGE  /ACRE CU FT CU FT BD FT /ACRE CU FT CU FT BD FT  SQFT CCF  FT   YRS CUFT/YR WEIGHT   STAND   MGMT
---- ---  ----- ----- ----- ----- ----- ----- ----- -----  ---- ---  ---  --- --- --- ------ -------- ----
1972  10   1171    98    84   475     0     0     0     0     5   5   19   10   8   0     18 EXAMPLE3 NONE
1982  20   1011   181   115   669     0     0     0     0    13  17   25   10  22   0     18 EXAMPLE3 NONE
1992  30    856   393   175   967     0     0     0     0    33  45   31   10  34   2     18 EXAMPLE3 NONE
2002  40    747   718   265  1425     0     0     0     0    62  81   36   10  49   6     18 EXAMPLE3 NONE
2012  50    640  1149   465  2433   396   407     0     0    54  61   38   10  49   5     18 EXAMPLE3 NONE
2022  60    208  1181   865  4486     0     0     0     0    80  84   42   10  44  10     18 EXAMPLE3 NONE
2032  70    179  1519  1304  6531     0     0     0     0    95  98   46   10  55  14     18 EXAMPLE3 NONE
2042  80    156  1923  1701  8641     0     0     0     0   111 111   51   10  42  15     18 EXAMPLE3 NONE
2052  90    137  2197  1994 10187     0     0     0     0   117 116   55   10  63  26     18 EXAMPLE3 NONE
2062 100    117  2568  2380 13363     0     0     0     0   127 123   60   10  57  24     18 EXAMPLE3 NONE
2072 110    103  2891  2710 14796     0     0     0     0   134 126   65    0   0   0     18 EXAMPLE3 NONE
```

(con.)

Example 3. (Con.)

ACTIVITY SUMMARY

STAND ID= EXAMPLE3   MANAGEMENT ID= NONE   EVENT MONITOR USER'S GUIDE EXAMPLE 3.

CYCLE	DATE	EXTENSION	KEYWORD	DATE	ACTIVITY DISPOSITION	PARAMETERS:			
1	1972								
2	1982								
3	1992								
4	2002								
5	2012	BASE	THINBTA	2012	DONE IN 2012	400.00	0.98	0.00	999.00
6	2022								
7	2032								
8	2042								
9	2052								
10	2062								

STAND GROWTH PROGNOSIS SYSTEM   VERSION 5.0 -- INLAND EMPIRE (TEST)

NOTE: PROCESSING STAND NUMBER: 1; STAND ID: EXAMPLE3 MGMT ID: NONE SAMPLING WEIGHT: 18.00000
BRANCHING: NODE=1, BRCH=3

SUMMARY STATISTICS (BASED ON TOTAL STAND AREA)

			VOLUME PER ACRE			REMOVALS PER ACRE							GROWTH				IDENTIFIERS	
YEAR	AGE	TREES /ACRE	TOTAL CU FT	MERCH CU FT	MERCH BD FT	TREES /ACRE	TOTAL CU FT	MERCH CU FT	MERCH BD FT	BA/ ACRE SQFT	CCF	TOP HT FT	PRD YRS	ACC CUFT/YR	MOR CUFT/YR	STAND SAMPLE WEIGHT	STAND	MGMT
1972	10	1171	98	84	475	0	0	0	0	5	5	19	10	8	0	18	EXAMPLE3	NONE
1982	20	1011	181	115	669	0	0	0	0	13	17	25	10	22	0	18	EXAMPLE3	NONE
1992	30	856	393	175	967	0	0	0	0	33	45	31	10	34	2	18	EXAMPLE3	NONE
2002	40	747	718	265	1425	0	0	0	0	62	81	36	10	49	6	18	EXAMPLE3	NONE
2012	50	640	1149	465	2433	0	0	0	0	93	116	38	10	63	16	18	EXAMPLE3	NONE
2022	60	515	1621	914	4644	0	0	0	0	121	142	41	10	60	26	18	EXAMPLE3	NONE
2032	70	407	1959	1490	6862	0	0	0	0	135	153	46	10	60	30	18	EXAMPLE3	NONE
2042	80	325	2258	1866	8746	0	0	0	0	144	159	51	10	75	40	18	EXAMPLE3	NONE
2052	90	258	2607	2274	11924	0	0	0	0	151	162	55	10	57	35	18	EXAMPLE3	NONE
2062	100	212	2824	2517	13021	0	0	0	0	152	159	58	10	68	42	18	EXAMPLE3	NONE
2072	110	174	3074	2798	14287	0	0	0	0	153	156	62	0	0	0	18	EXAMPLE3	NONE

U.S. GOVERNMENT PRINTING OFFICE: 1985-0-676-039/20023

Crookston, Nicholas L. User's guide to the Event Monitor: an addition to the Prognosis Model. General Technical Report INT-196. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 36 p.

Describes how to use the Event Monitor for scheduling Prognosis Model (Wykoff and others 1982) and Establishment Model (Ferguson and Crookston 1984) options, and for creating decision trees using the Parallel Processing Extension (Crookston in preparation). The program monitors certain statistics within the Prognosis Model and, when specified values are reached, schedules options that represent management activities.

KEYWORDS: simulation, forest, management, policy, growth

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**Intermountain
Research Station
Ogden, UT 84401**

General Technical
Report INT-197

January 1986

First Decade Plant Succession Following the Sundance Forest Fire, Northern Idaho

Peter F. Stickney

THE AUTHOR

PETER F. STICKNEY, plant ecologist, has served as project scientist on the Northern Rocky Mountains Forest Wildlife Habitats research work unit at Missoula since its inception in 1962. His work focuses on the plant ecology of upland wildlife habitats associated with big game, being principally concerned with the nature and development of seral forest vegetation following disturbance by logging or fire. He was involved in research on mountain grasslands in the Northern Rockies from 1957 to 1962. Prior to this, he did range allotment analysis work on the Malheur National Forest in eastern Oregon. He holds a B.S. in forestry from the University of Idaho and an M.S. in botany from the University of Wisconsin, and is a member of the Ecological Society of America, Society for Range Management, and California Botanical Society.

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RESEARCH SUMMARY

First 10 years of development and change in vegetation established following disturbance by a holocaustic forest fire were documented by annual sampling of permanent plots. While species composition was relatively complex (about 140 species), less than 10 percent accounted for most of the seral vegetation developed during the first decade. Four species in particular (*Epilobium angustifolium*, *Pteridium aquilinum*, *Ceanothus sanguineus*, *Salix scouleriana*) provide more than half of the vegetation produced during the decade. The composite pattern for secondary forest succession exhibited an initial herb stage of 4 years duration succeeded by a shrub-predominant stage that continued through the first decade. Succession patterns on individual sites began with either herb- or shrub-predominant initial communities. The duration of the initial herb stage was largely dependent on the composition of the shrub component and ranged from 1 to 10 or possibly more years. Tree-dominant communities did not develop in the first 10 years.

The pattern and rate of succession on individual sites appears to be primarily dependent on the combination of surviving and colonizing plant species comprising the initial postfire community. This study documents that sequential replacement of initial species by secondary species subsequently established has not occurred. Rather, the process of successional development that appears to be paramount in the first postfire decade is one of differential development of the species established in the initial community.

First Decade Plant Succession Following the Sundance Forest Fire, Northern Idaho

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INTRODUCTION

Prior to settlement, secondary forest succession in the Northern Rocky Mountains was initiated principally by wildfire. Fire was a frequent and recurrent element of these forest ecosystems, as noted by many investigators, including Leiberg (1899, 1900), Ayres (1900a, 1900b), Marshall (1928), Daubenmire and Daubenmire (1968), Wellner (1970), Habeck and Mutch (1973), Norum and others (1974), and Arno (1976, 1980). Forest fires varied in intensity from light ground fires to severe crown fires (Ayres 1900a; Arno 1976; Wellner 1970). Although the severity of fire characteristic for this region has been the subject of some discussion (Wellner 1970; Arno 1976, 1980), Larsen and Delavan (1922) point out that regions in the Northern Rocky Mountains with the highest total precipitation, but with dry summers that average less than 2 inches (5 cm) of precipitation per month, are more likely to experience high-intensity holocaustic fires when they do burn.

Holocaustic burns represent the severest natural fire disturbance of forest vegetation in the Northern Rocky Mountains. A holocaustic fire burns with a severity sufficient to destroy all the aboveground portion of the vegetation, as evidenced by (1) all coniferous trees killed, (2) crowns of both understory and ground-layer vegetation consumed or killed back to the ground, and (3) the organic mantle of the forest floor reduced to ash down to the mineral ground surface (fig. 1).

The Sundance Fire of 1967 was representative of this kind of fire disturbance and was comparable to the major fires that burned in this forest region during the early decades of this century (Spencer 1957; Koch n.d.). Similarly, the Sundance Fire occurred at the height of the fire season in the normally dry period of late summer. Ignited by a lightning strike on Sundance Mountain in the Selkirk Range of northern Idaho, it smouldered for 12 days before breaking out on August 23. In the next 10 days, it burned 56,000 acres (22 663 ha) of forest land. The largest portion of this area, 50,000 acres (20 235 ha), burned in a 9-hour period on September 1. During this time it became an intense, running crown fire that reached "fire storm" proportions as it burned over the study location in the Pack River Valley (Anderson 1968).

Occurring after three decades of increasingly effective fire suppression, the Sundance Fire provided a unique opportunity to examine the response of forest vegetation returned to its most elemental initial conditions for secondary plant succession. The severity of this burn also provided an opportunity to observe features that enable forest plant species to survive extreme natural fire disturbance.

Figure 1.—Results of disturbance by Sundance forest fire. The severity of this fire treatment destroyed the overstory and understory layers of the stand and reduced the organic mantle of the forest floor to ash down to the mineral soil surface, thereby returning the forest vegetation to its most elemental condition for initiating secondary succession.

This paper describes the development of seral vegetation for the 10 years following the holocaustic Sundance Fire in the western redcedar-western hemlock forest type in northern Idaho. Successional development of seral vegetation was documented by repeated measurements on permanent plots.

PRIOR WORK

Inspectors of the then newly established Federal Forest Reserves observed forest succession in the Northern Rocky Mountains following fire as early as the late 1800's (Leiberg 1897, 1899; Ayres 1900a, 1900b). Succession was described in terms of trees, shrubs, grasses, and "weeds." The emphasis was on the tree component and its successional status.

Leiberg (1897) provides one of the earliest descriptions of forest succession in northern Idaho for the "white pine zone." He describes secondary plant succession following "first burns" in these forests as progressing through three periods of "forest recovery." The first, within a few months after the fire, showed the establishment of young plants of willow and *Ceanothus* and, if near a timbered edge, conifer seedlings. After 3 or 4 years, a second period was characterized by the accumulation of humus from the litter of deciduous shrubs and herbaceous plants that "appear to be essential to the germination of the seeds of conifers." Replacement of shrubby vegetation by a thriving growth of young trees marked the beginning of the third period. Leiberg also recognized a difference in the duration of the early seral stages in the case of "second burns." Under these conditions young trees were destroyed by another fire that made the site "too dry" for tree reestablishment and allowed other forms of vegetation to dominate the site for long periods.

Two years later, Leiberg (1899) expanded his description of the "reforestation process" in the white pine zone to include five phases. The first three phases were distinguished by the sequential prominence of: (1) herbaceous plants—mosses and fireweed (*Epilobium angustifolium* L.); (2) shrubby plants—snowbrush (*Ceanothus velutinus* Dougl.), redstem (*C. sanguineus* Pursh), *Salix flavescens* Nutt., western serviceberry (*Amelanchier alnifolia* [Nutt.] Nutt.), and quaking aspen (*Populus tremuloides* Michx.); and (3) lodgepole pine (*Pinus contorta* Dougl. ex Loud.). In the third phase, Leiberg characterized the influence of the density of lodgepole pine on the preceding vegetation as "soon driving out nearly all other vegetation, herbaceous and shrubby." The fourth phase followed after 25 to 35 years with thinning out of the lodgepole pine and establishment of tree "species of the original forest." The fifth phase represented the development of the original forest species toward old growth.

After the "Great Idaho Fire of 1910," Humphrey and Weaver (1915) observed that the initiation of succession on heavily burned soils in this region often began with an abundant ground layer of firemoss (*Funaria hygrometrica* Hedw.) and liverwort (*Marchantia polymorpha* L.). Somewhat later, Larsen (1929) presented a generalized description of postfire forest succession for northern Idaho in which two of three stages of "subordinate" vegetation precede the first of three tree overstory stages. Pioneer herbaceous and low shrub species characterize the first subordinate stage. After 2 or 3 years these give way to a second stage, characterized by perennial plants that produce berries or berrylike fruit. Larsen states that these plants served as a nurse crop to establishing conifer seedlings by "shading and sheltering" and contributing to the rapid accumulation of leaf mold. The third subordinate stage began in 8 to 10 years with the overtopping of the second stage by the emerging young conifer trees and the replacement of the "berry species" by "somewhat uninfluential and unassuming" species tolerant of overstory shading. As the coniferous overstory developed into a climax forest condition, the third subordinate stage was eventually replaced by climax understory of perennial evergreen species. The process of forest succession for the climax cedar-hemlock-grand fir forest, Larsen believed, was one in which each preceding understory and/or overstory stage "improves the site and paves the way" for the succeeding successional stage.

In a more recent interpretation of forest succession in the Northern Rockies, Daubenmire and Daubenmire (1968) characterized succession following fire or timber harvest as a sequential process involving three stages keyed to tree development: (1) "invasion," (2) "stagnation," and (3) "resumption of regeneration." The "invasion" stage contains surviving sciophytic (shade plant) shrubs and herbs and heliophytic (sun plant) tree, shrub, and herb species that invade the site from outside the burned area. This stage continues for a decade or two, depending on the distance to tree seed source, and terminates when the crown closure of the young coniferous trees marks the beginning of the "stagnation" stage. In this second stage there are no further additions to species composition from outside sources. Coniferous overstory development continues, and the denser canopy intensifies shading that permits the survival of only the most sciophytic undergrowth plants. The stagnation stage witnesses the replacement of fast-growing tree species by slower growing ones and ends with the eventual maturity of the climax tree species.

The initiation of the last, or "regeneration," stage is marked by the readmittance of light to the forest floor as a result of overmaturity and death in the climax tree stand. Seedlings of the most shade-tolerant trees, shrubs, and herbs, restricted to sun-fleck aggregations in earlier stages, diffuse across the forest floor as the shading intensity of the overstory becomes less severe.

In the process of forest succession, the Daubenmires note that all members of the various seral dominants, plus climax tree species, may become established in the first year of succession, and that it is the differential rates of development to maturity that serve to distinguish successive seral stages. They further note, in contrast to Larsen and others, that there is little evidence that the dominants of any seral stage require modification of the ground surface environment to enable their establishment.

Lyon's permanent plot studies of vegetal development following prescribed burning and wildfire represent the first work on forest succession in the Northern Rocky Mountains based on sampling actual changes in postfire vegetation. In the first of these studies, Lyon (1971) reports seral development for 7 years following a prescribed burn of a standing Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) forest on the Sawtooth National Forest in central eastern Idaho. Herbaceous plants represented the dominant life form of the initial successional stage. Community dominants during the first 5 years were three species of herbs. A biennial, *Dracocephalum parviflorum* Nutt. (syn. *Moldavica parviflora* [Nutt.] Britt.), was the predominant species in the first 2 years of succession. At its maximum development in the second year it was the most abundant species and provided 37 percent cover. Thereafter, two perennial herbs, fireweed and wild hollyhock (*Iliamna*

rivularis [Dougl.] Greene), were the most abundant species, collectively providing about 20 percent cover until the sixth year. Snowbrush became the dominant plant species in that year. Lyon suggests that shrubs will dominate to about the 30th year, or until overtopped by trees.

In a second study conducted on the Bitterroot National Forest in western Montana, Lyon (1976) documented early postfire vegetal development in a high-elevation lodgepole pine forest following wildfire. Aerially seeded, exotic herbaceous species formed the initial cover group for the first 3 years, after which native herb and low shrub species comprised the dominant group. Maximum cover values for introduced herbs were reached in the sixth year and for native species in the eighth year. By the 12th year, coverage for the introduced group had declined by two-thirds, but coverage for the native group remained at 90 percent of maximum values. These changes took place in the presence of the establishment of dense stands of lodgepole pine, which developed into a prominent tree component on most study sites after the eighth year. The absence of a well-developed shrub component in the majority of these seral communities resulted in a successional sequence that proceeded directly from an herb to a tree stage. The study covered 12 years, during which various forest management activities superimposed on most of the study sites compromised the original objective. In spite of these postfire management disturbances, a general successional trend from herb to tree prominence was still evident.

STUDY AREA

The Pack River Valley is the principal drainage traversing the Selkirk Range in northern Idaho. In this valley, 18 study areas were located at elevations between 2,900 and 4,300 feet (880 and 1 310 m) in T. 60 N., R. 2 W., B.M., 20 miles (32 km) north of Sandpoint, ID. All but three of the study sites are within a 2-mi^2 (5.18-km^2) area within sections 8 and 9, nearly a mile (1.6 km) from the nearest burn edge.

Landforms in the prominent mountain valley of the Pack River, cut into the granite of the Kaniksu Batholith, have been modified by glaciation (Alden 1953). The resulting topography at middle and low elevations is moderate in relief, with rounded interior ridges and generally uniform slopes. Moderate areas of smoothed granitic bedrock outcrop on interior ridges and spurs from midslope upwards. Study sites represent all four cardinal exposures and slopes that range from 15 to 50 percent (modal value 30 percent). Soils of the valley flank derive from granitic tills overlaid by a loess cap of yellowish-brown silt loam 6 to 30 inches (15 to 76 cm) thick (USDA Forest Service n.d.). These mountain soils are regosolic in character and contain a low volume of coarse, angular fragments of granitic rock.

The climate of the Selkirk Range in northern Idaho is unusually moist for inland mountains in the Pacific Northwest (Arno 1970). Arno, using a modified version of the Koeppen [Köppen] system (Critchfield 1966), classifies this mountain climate as a maritime influence type (Koeppen's Df'), which is characterized by high annual precipitation and maritime, snowy winters. Although the mean annual precipitation for the adjacent valley stations at Sandpoint Experiment Station and Priest River Experiment Station is 33 and 32 inches (84 and 81 cm), respectively (Rice 1971), the annual precipitation for the general area of the study is estimated to be in the 40- to 60-inch (102- to 152-cm) range (Rice 1971). At the Priest River Experiment Station, 15 miles (24 km) southwest of the Sundance study area, about 75 percent of the precipitation falls in the dormant season (October through April), mostly as snow. The driest months are July and August, with minimum monthly precipitations at the valley stations between 0.5 and 1 inch (1.27 and 2.54 cm). Annual mean temperatures at these two stations are 44 and 45 °F (24.4 and 25.0 °C), respectively, and the coldest monthly means (January) are 6 and 8 °F (3.3 and 4.4 °C) below freezing, respectively. The mean frost-free season at Priest River Experiment Station is relatively short—88 days, from June to September. Thus, for the valleys at medium to lower elevations within the Selkirk Range, the dormant season is relatively long, cool but not cold, and moist, while the growing season is relatively short, warm, and dry, but not particularly droughty.

Under these climatic conditions, forest vegetation has been characterized by Daubenmire (1952) as belonging in the *Thuja-Tsuga* zone. Although it was difficult to determine after the fire, most of the study sites appeared to best fit Daubenmire's (1952) *Thuja-Tsuga/Pachistima* association on the basis of (1) the general prefire presence of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), (2) the composition of the tree component (up to 11 species) of the prefire forest, (3) the greatest proportion of surviving indicator species represented by the *Pachistima* union, and (4) the high presence in the general area of the most typical species of this union. As expressed in the later refinement of this classification, all but the most xeric sites would probably represent the *Tsuga heterophylla/Pachistima myrsinites* habitat type (Daubenmire and Daubenmire 1968).

METHODS

Shortly after control of the Sundance Fire, 20 sites in the burn were selected for study of vegetation response to a severe wildfire treatment. Criteria for site selection included (1) upland well-drained area, (2) uniform slope and exposure, (3) uniform burning treatment, (4) free of mechanical disturbance, and (5) representation of the range of prefire communities as evident from their postfire physiognomic remains. Study sites included old forest (large trees), young forest (dense, smaller trees), clearcut old forest, and brushfield. Study plots were installed the following summer on 17 sites that remained free of disturbance from timber salvage logging and on one additional burned brushfield site.

Seral vegetation development was measured on permanent plots using nondestructive sampling techniques. (Study was designed and executed in metric; thus only metric units are reported for the methodology.) Each study area consisted of two 5- by 25-m transects. The downhill edge of each transect served as a permanently

marked baseline to which all sample plots were referenced. Each transect consisted of five contiguous 5- by 5-m blocks. Each block contained three nested square plots of 1.5, 3, and 5 m. Woody plants over 0.5 m high were stratified into three height classes and sampled in their respective size-nested plots. Height classes and associated plot sizes are given in table 1. For each transect, herbaceous and low woody plants (including shrubs and trees less than 0.5 m high) were sampled in 10 plots of 0.5- by 0.5-m regularly arrayed along the baseline.

The diameter of trees over 2.5 m high was measured at a height of 1.4 m to the nearest centimeter. Trees less than 2.5 m but more than 0.4 m high were counted by species. Those 1.5 to 2.5 m in height were assigned a diameter of 1.25 cm. The aerial crown cover of each shrub and tree over 0.5 m high and rooted within the plot was sampled, as if it were an ellipse, by measuring its long axis and one at right angles to it. The height of the aerial crown above its rooted point was also measured. All crown measurements were made to the nearest decimeter. Crown area coverage of all herbaceous and low woody species (including shrubs and trees less than 0.5 m high) was estimated to the nearest one-sixth of the 0.5- by 0.5-m plot. The representative height within the plot was measured to the nearest half decimeter. Aerial crowns of herb and low woody species covering less than one-sixth of the plot were grouped and treated as miscellaneous vascular vegetation. Ground surface not covered by vascular vegetation was classified as (1) moss and lichen, (2) litter, (3) rock, or (4) bare ground, and cover estimated in units of one-sixth of the plot. All herb and low woody species occurring within the plot were recorded for frequency. The presence of all species within the vicinity immediately adjacent to the transect was recorded.

Tree diameters were converted to basal area. Cover for shrubs and trees over 0.5 m high was calculated as the area of an ellipse. The volume of space occupied by these shrubs and trees was represented as a cylindroid and computed as the product of the crown area and the height. Cover of herbs and low woody plant species (including shrubs and trees less than 0.5 m high) was determined directly from estimated units of area. Volume of space occupied for these plants was computed as the product of the area and the measured representative height. All attributes quantifying species abundance were standardized to a 0.01-ha base.

Table 1.—Summary of permanent plots and associated vegetation sampled for a study area

Plot size	Height limits	Vegetation sampled	No./study area
------- Meters -------			
5 × 5	2.5 +	Shrubs and trees	10
3 × 3	1.5-2.45	Shrubs and trees	10
1.5 × 1.5	0.5-1.45	Shrubs and trees	10
0.5 × 0.5	<0.5	Shrubs and trees and all herbaceous plants	20

Botanical nomenclature follows Hitchcock and Cronquist (1973). Identifications of plant species were made by the author with verification of most species by Frederick J. Hermann and Charles Feddema, both formerly of the USDA Forest Service Herbarium, formerly in Fort Collins, CO. Voucher specimens for most species are on file at the Forestry Sciences Laboratory Herbarium, Missoula, MT (MRC), with duplicates at the Forest Service Herbarium (USFS).

SERAL ORIGINS

In the following sections, early phases of secondary forest succession are described in terms of species' dominant life form and composition. Each section represents a less inclusive and more specific examination of the plant community and associated structural changes over time. In clarifying these relationships, it is necessary first to provide an outline of the sources of plant species involved in succession.

When defined by source and time of establishment, postfire vegetation consists of four groups: (1) survivors, (2) residual or onsite colonizers, (3) initial offsite colonizers, and (4) secondary offsite colonizers (table 2). Survivors are those species with established plants on the site at the time of the fire that were capable of regrowth after burning. Regrowth for nearly all survivors was evident by the end of the first postfire growing season. Occasionally, shade-tolerant species that normally do not survive severe burning treatments will appear above ground in the second or third year after a fire as resprouts from underground plant parts (Hutchinson and Freedman 1978). On the Sundance Burn three species have been identified with this response pattern and have been designated as accidental survivors in the appendix.

Table 2.—Composition of seral vegetation on the Sundance Burn by origin, source, and initial flora, 1968 through 1977

Compositional component	No. of species	Percent
Seral origin		
Survivors[1]	64	46
Residual colonizers	16	12
Initial offsite colonizers (SY:1)[2]	28	20
Secondary offsite colonizers (SY:2–10)[2]	31	22
Total	139	100
Source		
Onsite (survivors, residual colonizers)	80	58
Offsite	59	42
Total	139	100
Initial postfire flora (SY:1)[2]		
Survivors	59	42
Residual colonizers	16	12
Initial offsite colonizers	28	20
Total	103	74

[1]Includes three secondary survivor species (plants first detected in SY:2 or 3 not of seedling origin).
[2]SY:1 = Succession year 1; designates the number of years (growing seasons) since the fire.

Colonizers are species that establish new plants from postfire seedlings. Residual colonizers originate from seeds or fruits present on the site at the time of the fire. Seeds of residual colonizers are adapted to withstand burning in the fuel concentrations in which they naturally occur or survive occasionally by the protective circumstances of locations in which they chance to occur. Onsite seed sources occur either in the overstory canopy or on the forest floor (ground stored). The residual colonizer group includes species with apparently both long- and short-lived seed. Offsite colonizers are species that originate in unburned areas. Characteristically, the seed or fruit of these species is capable of relatively long-distance dispersal. Their requirements for germination and seedling establishment are usually those of ruderal (pioneer or weedy) plants. Viability of their seed is typically short lived. Secondary colonizers differ from initial offsite colonizers in their later time of arrival after the initial plant community has become established. Seedlings of secondary colonizers must be capable of establishing in closed or partially closed plant communities. For this report, species derived from offsite sources that appeared after the first year were designated secondary colonizers.

Nearly half of the species comprising the postfire flora were survivors. And most of the remainder (colonizers) were also present in the first postfire year. Survivors represented the largest and residual colonizers the smallest seral origin groups of species constituting the postfire flora in the first year (table 2). Collectively, these two groups compose that element of the postfire flora derived from onsite sources. Even with the severe burning treatment effected by this fire, nearly 60 percent of the total species composition originated within the burned area. Survivors represented the principal source for species revegetating the burn in the first 10 years. By the end of the decade, survivors still represented the largest group of species on half the study sites. On the remaining half, secondary colonizers constituted the largest source of species.

Most species (90 percent) showed only one seral origin. However, 14 species displayed the capability to function both as survivors and colonizers (appendix). For example, fireweed, an important early seral perennial herb, functioned primarily as an initial offsite colonizer by means of a light, air-mobile seed capable of long-distance dispersal. But occasionally it responded as a survivor regrowing from deep-seated rhizomelike roots. Redstem, a pioneer shrub, exhibited another combination of seral origins. When present on a site prior to the fire, it functioned as a survivor by regrowing from burned root crowns. More commonly, redstem functioned as a residual colonizer by establishing seedlings from long-lived seed stored in the ground. For those species with more than one seral origin, the summary in table 2 gives priority to the survivor classification.

SPECIES COMPOSITION

The flora of the seral vegetation developing over the first 10 years on 18 study areas was composed of 139 species of vascular plants (appendix). Of these species, 73 percent were detected in plot sampling. The remainder occurred in the immediate vicinity of the sampling plots. On individual sites floristic composition averaged 53 species and ranged between 43 and 70 species. The degree of uniformity in species composition between sites was relatively low. Only eight species were present on all study sites while an additional 40 species occurred on at least half of the sites. Thirteen species accounted for most of the seral vegetation produced in the first decade of succession (table 3).

Table 3.—Principal and secondary cover species of the first decade's seral vegetation on 18 study areas in the Sundance Burn

Cover species	Present	CS[1]	PCS[2]	Maximum cover
	- No. of study areas -			*Percent*
PRINCIPAL				
Alnus sinuata	10	6	1	15
Amelanchier alnifolia	14	4	3	15-41
Anaphalis margaritacea	18	13	1	16
Betula papyrifera	8	2	2	16-48
Calamagrostis rubescens	10	4	2	24-33
Ceanothus sanguineus	14	10	8	36-183
Epilobium angustifolium	18	18	14	22-72
Lupinus argenteus	3	3	1	25
Pachistima myrsinites	18	13	2	15-20
Pinus contorta	15	5	1	47
Pteridium aquilinum	15	14	10	19-59
Rubus parviflorus	15	13	4	16-31
Salix scouleriana	18	18	17	16-75
SECONDARY			SCS[3]	
Acer glabrum	12	4	2	5-8
Agrostis alba	12	3	1	11
Apocynum androsaemifolium	12	4	2	10-14
Arnica latifolia	2	1	1	6
Carex rossii	17	10	5	5-9
Ceanothus velutinus	6	4	1	13
Dactylis glomerata	9	3	1	6
Geranium bicknellii	5	3	2	6-11
Hieracium albiflorum	18	6	1	5
Holodiscus discolor	6	3	3	5-11
Prunus emarginata	5	3	1	9
Pseudotsuga menziesii	18	9	2	5
Rosa gymnocarpa	11	8	3	8-9
Rubus leucodermis	7	4	1	5
Spiraea betulifolia	8	5	3	10-13
Symphoricarpos albus	4	4	1	11
Thalictrum occidentale	7	2	1	5
Vaccinium membranaceum	17	6	1	10
Xerophyllum tenax	8	3	1	11

[1]Cover species (1+ percent cover).
[2]Principal cover species (15+ percent cover).
[3]Secondary cover species (5-14 percent cover).

Herbs comprised the largest life-form group of species (table 4). Over one-fourth of the herb species were exotics (appendix), and nearly half of these were annuals or biennials. The majority of exotic annual and biennial species behaved as casual introductions. One-third of the exotics were intentional introductions associated with postfire rehabilitation seeding. Although more than half of these species have persisted throughout the first decade, none have become prominent elements in the seral vegetation. Only two exotics, both pasture grasses, redtop (*Agrostis alba* L.) and orchard-grass (*Dactylis glomerata* L.), developed sufficiently to exceed 5 percent cover.

Of all the species recorded for the decade, 74 percent were present in the first postfire year. Changes in floristic composition involved 51 species. Herbs accounted for most of these changes, with casual exotics the most characteristic of those disappearing and native perennial herbs accounting for most of the additions. Of the 23 shrub species present at the end of the decade, 21 were present in the first year. The number of tree species, however, increased from five to 11, in part because of reforestation plantings.

SPECIES DISTRIBUTION DEVELOPMENT

Eighty-one of the 101 species detected (sampled for frequency) in the half-meter herb plots showed a near-steady-state pattern, with little expansion or reduction of their distributions within the site of a study area. Throughout the decade their occurrence (frequency) remained within a range of about 25 percent. The distribution of 74 of these species was limited (5 to 30 percent frequency). Beargrass (*Xerophyllum tenax* [Pursh] Nutt.), spirea (*Spiraea betulifolia* Pall.), and seedling lodgepole pine exhibited a somewhat wider distribution with occurrences between 35 and 65 percent frequency on at least one study area. Most widely distributed of the species showing only the steady-state distribution pattern were Ross sedge (*Carex rossii* Boott), lupine (*Lupinus argenteus* Pursh), mountain-box (*Pachistima myrsinites* [Pursh] Raf.), and thimbleberry (*Rubus parviflorus* Nutt.). Each of these species maintained frequencies between 70 and 100 percent on at least one study area throughout the decade.

One-fifth of the species sampled for frequency exhibited changes that exceeded 30 percent during the decade, thereby demonstrating a marked expansion or reduction of their occurrence within the community. For the group showing a decrease, the only woody plant species declining in frequency were seedlings of paper birch (*Betula papyrifera* Marsh.), redstem, and Scouler willow (*Salix scouleriana* Barratt ex Hook.). Shade-intolerant herbs characterize the remainder of this group. Within 3 to 5 years geranium (*Geranium bicknellii* Britt.), cudweed (*Gnaphalium microcephalum* Nutt.), and rye (*Secale cereale* L.) declined in frequency from 50, 40, and 85 to 0 percent, respectively. Geranium and rye became locally extinct at all sites, but cudweed was still present on a few sites at the end of the decade. In 7 years white clover (*Trifolium repens* L.) declined from 45 to 0 percent in frequency, showing its widest distribution in the first year. On three of the drier sites fireweed declined in frequency between 35 and 65 percent. On nearly all other sites it maintained a frequency between 100 and 75 percent throughout the decade.

Sustained increase in frequency indicative of expanding populations resulted from either the establishment of new plants from seedlings or from vegetative ingrowth. In total, 13 species displayed increases in frequency, exceeding 30 percent within the first decade on at least one site. Seven of these increased by seeding in: Sitka alder (*Alnus sinuata* [Regel] Rydb.), pearly-everlasting (*Anaphalis margaritacea* [L.] B. & H.), paintbrush (*Castilleja miniata* Dougl.), cudweed, hawkweed (*Hieracium albiflorum* Hook.), tiger lily (*Lilium columbianum* Hanson), and round-leaved violet (*Viola orbiculata* Geyer). Three species with rhizomes but no observed seedlings increased by vegetative ingrowth: dogbane (*Apocynum androsaemifolium* L.), bracken fern (*Pteridium aquilinum* [L.] Kuhn.), and huckleberry (*Vaccinium membranaceum* Dougl.). Three species with rhizomes and seedlings present increased by both processes: redtop, arnica (*Arnica latifolia* Bong.), and pinegrass (*Calamagrostis rubescens* Buckl.).

Table 4.—Life form composition of seral vegetation on the Sundance Burn study areas, 1968 through 1977

Life form component	Species composition: Number	Percent	Number exotic[1]	Number introduced[2]
Tree	11	8	—	—
Shrub	23	16	—	—
Herb	105	76	29	7
Perennial[3]	80	58	16	6
Biennial	7	4	2	—
Annual	18	14	11	1
Totals	139	100	29	7

[1]Species not indigenous to the flora of the region.
[2]Intensional exotic introductions (included in exotic column).
[3]Includes low woody plant species.

Among those species that expanded their distributions in early succession, the most prominent examples include bracken fern, pearly-everlasting, Sitka alder, and hawkweed. Maximal distribution expansion of bracken fern from rhizome elongation increased frequency from 50 to 100 percent in 8 years on one site and from 15 to 70 percent in 10 years on another. Pearly-everlasting (initial offsite colonizer) arrived on all study areas between the first and third years. With few exceptions, seedlings first appeared in the frequency plots in the second to fourth years. Over the remainder of the decade, this species expanded its distribution on nine study areas attaining frequencies of 70 to 100 percent. Hawkweed (secondary offsite colonizer) arrived later than pearly- everlasting, appearing on most study areas between the fourth and fifth years. Seedlings were first detected in frequency plots in the fifth to seventh years. Frequencies of this species on half of the study areas increased from 0 to between 40 and 95 percent by the 10th year. Sitka alder was the only shrub to expand its distribution by seeding in following the establishment of the initial seral vegetation. On one study area, alder resprouts from surviving root crowns first flowered when they were 5 years old. Seedlings first detected in the eighth year at the 5 percent frequency level increased to 75 percent 2 years later. Cudweed was the only species that exhibited both increases and decreases in its distribution that exceeded 30 percent frequency within the first decade.

SERAL VEGETATION DEVELOPMENT

Development of seral vegetation is described in terms of the successional change of its principal life-form components (herb, shrub, and tree). The life form with the greatest coverage was adopted as the basis for designating successional stages. Patterns of seral vegetation development are characterized by the order and duration of the dominant life form.

Less than half of the seral flora became abundant members of the seral vegetation (table 5). Only one-fourth of the species attained coverages of at least 5 percent. The general character and appearance of vegetation at individual study sites was dependent on 13 principal species (table 3). However, only four species of this latter group produced the greatest part of the vegetation developed during the decade (63 to 76 percent cover annually). Two of these species were herbs (fireweed and bracken fern) and the other two were shrubs (redstem and Scouler willow).

Composite Successional Pattern

The general pattern emerging for the first decade of forest succession in the Sundance Burn derived from a composite of all study areas indicates a rapid development of vegetative cover (100 percent by the fifth year) in which the early prominence of herbs was succeeded after the fourth year by a shrub-dominant community (fig. 2-1). The rapid initial development of seral vegetation was largely due to the colonization of fireweed. Following the peak of fireweed development, usually in the second year, the regrowth of bracken fern mainly accounts for the maintaining of the coverage of the herb component (fig. 2-2) in the presence of the rapidly developing shrub stand. Averaged over all areas, the development of redstem and Scouler willow shrubs contributed about equally to the increase in vegetative cover and accounted for most of the shrub cover developed during the decade (fig. 2-3). In the absence of the development of a significant tree component, much of the vegetation of the Sundance Burn should remain in the shrub stage well into the second decade, if not longer.

Table 5.—Abundance components of Sundance Burn seral vegetation, 1968 through 1977

Component	No. of species	Percent of seral flora
Species sampled as cover:		
Principal cover species (15 + percent cover)	13	9
Secondary cover species (5-14 percent cover)	19	14
Cover species (1-4 percent cover)	27	19
Total cover composition	59	42
Species sampled as frequency	101	73
Species sampled as presence	139	100

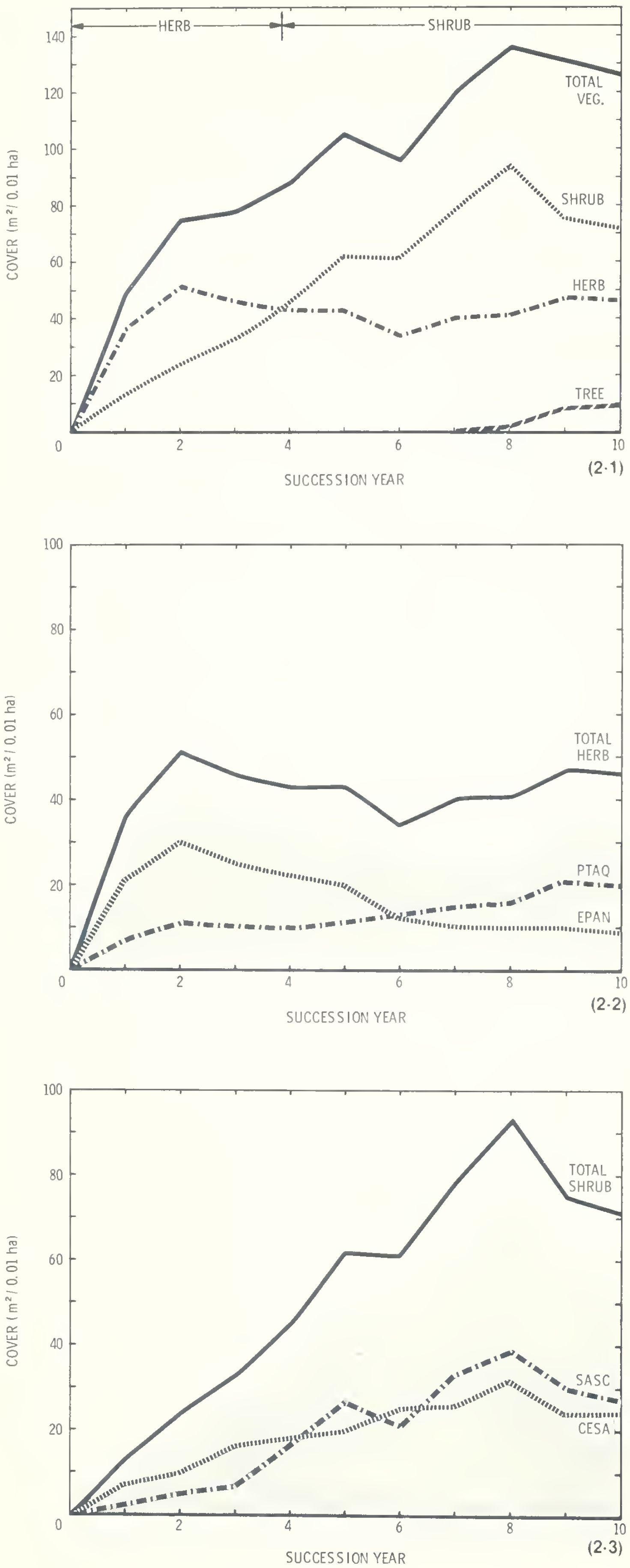


Figure 2.—Composite development of seral vegetation on Sundance Burn for 18 study areas: (2-1) total vegetation and life-form components; (2-2) major herb component species: *Epilobium angustifolium* (EPAN) and *Pteridium aquilinum* (PTAQ); (2-3) major shrub component species: *Ceanothus sanguineus* (CESA) and *Salix scouleriana* (SASC). Shaded areas indicate the amount of cover contributed by the two principal secies of each life-form component.

Range of Seral Development Patterns

The sequence of successional stages in the first 10 years for all but seven study areas followed the composite pattern from an herb- to shrub-dominated community. The exceptions exhibited no sequential development and maintained their initial stage throughout the decade. Four study areas in this group remained herb dominated while three study areas began and remained shrub dominated. Between these extremes in herb stage duration the remaining study areas exhibited a broad array of seral patterns. The development of vegetative cover ranged from nearly twice to less than half that for the composite. Nearly two-thirds of the sites attained maximum coverage between the seventh and ninth years. For the remaining study areas cover continued to increase throughout the decade. The extent of the cover development spectrum observed on the Sundance Burn ranged from an herb stage that lasted throughout the decade to one in which the rapid regrowth of shrubs excluded the herb stage altogether (fig. 3).

Extended Herb Stage Sequence.—For study areas exhibiting this pattern, herbs constitute the most abundant cover group throughout the first decade (fig. 4). This pattern of development was associated with a prominent herb component composed of both survivor and colonizer species, a minimal shrub component represented by few survivor plants or slowly developing species, and a nearly absent to latent tree component. Of the four study areas characterizing this pattern, SD-05 exemplifies the maximal development of the herb component (fig. 5-1). Rapid initial development of the herb component resulted from the abundant establishment of fireweed (100 percent frequency in the first year). Regrowth from an extensive survivor stand of bracken fern (first-year frequency 65 percent) was largely responsible for maintaining high herb coverage following the early peak of fireweed development (fig. 5-2). Few survivor shrubs were present. The shrub component was composed mainly of Scouler willow seedlings. Consequently, shrub coverage was slow in development and remained low for most of the first decade (fig. 5-3).

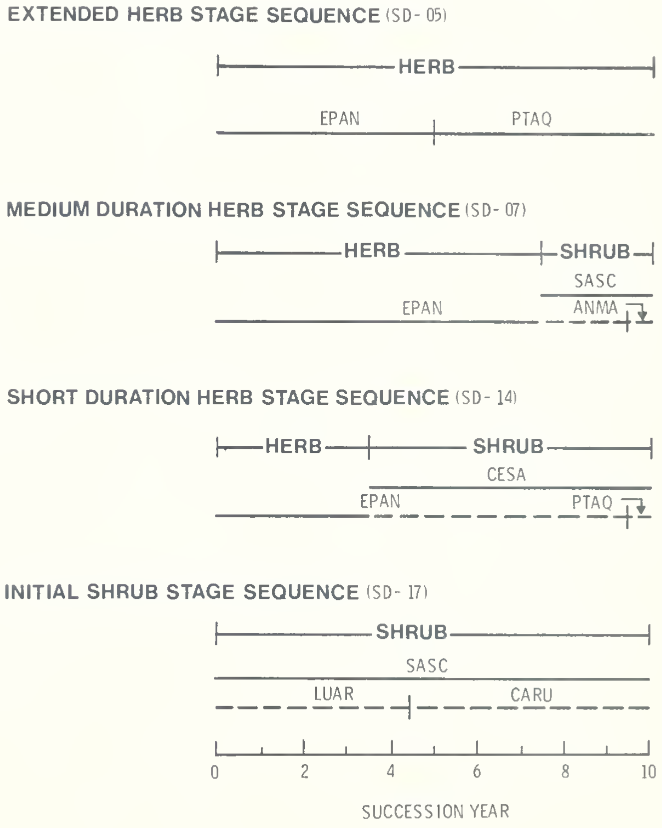


Figure 3.—Patterns of successional stages representing the spectrum of early seral development, Sundance Burn, and duration of dominant cover species associated with the development of each life-form component. Solid species line: overstory cover species; dashed species line: understory cover species. ANMA = *Anaphalis margaritacea*, CARU = *Calamagrostis rubescens*, CESA = *Ceanothus sanguineus*, EPAN = *Epilobium angustifolium*, LUAR = *Lupinus argenteus*, PTAQ = *Pteridium aquilinum*, SASC = *Salix scouleriana*.

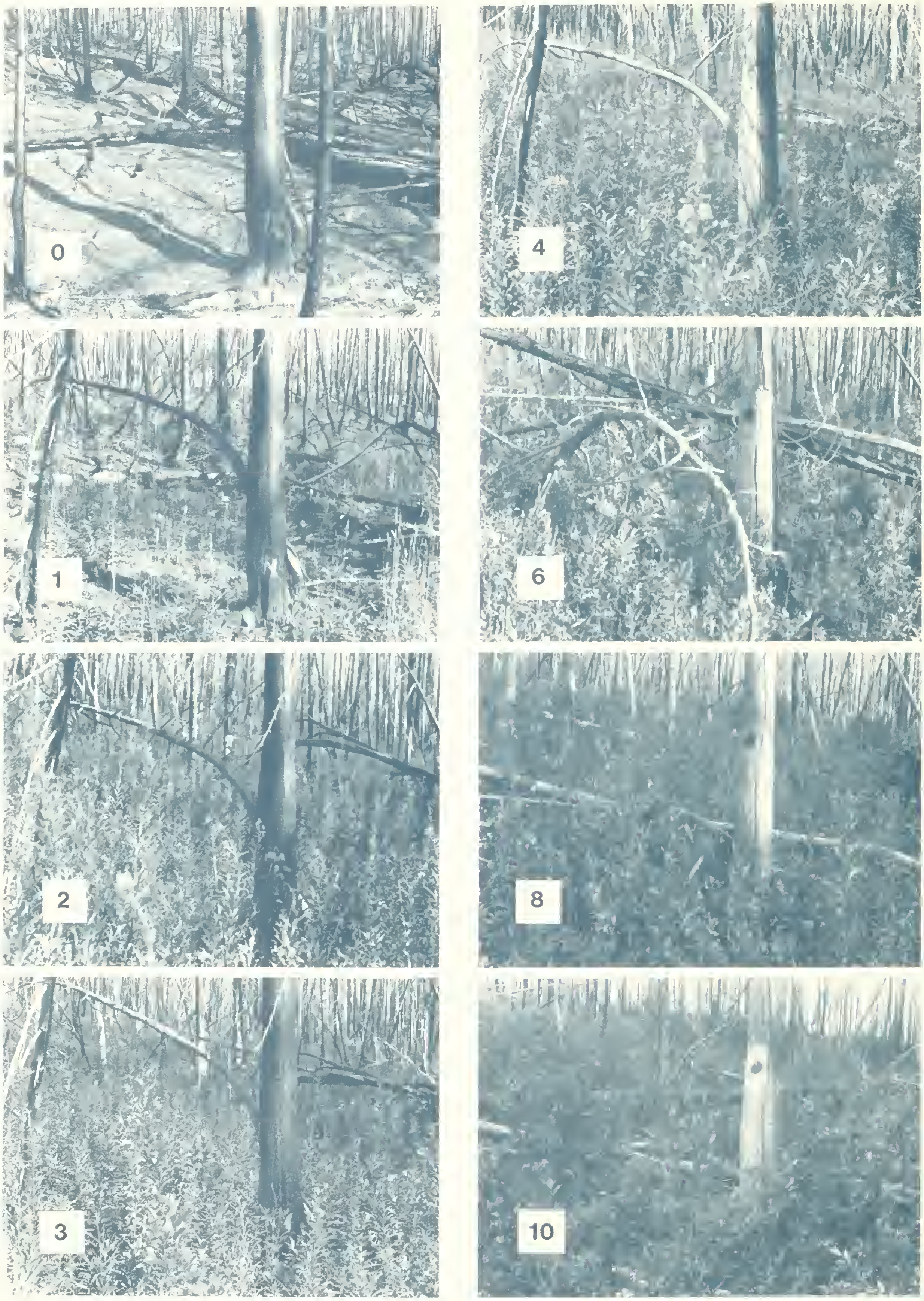
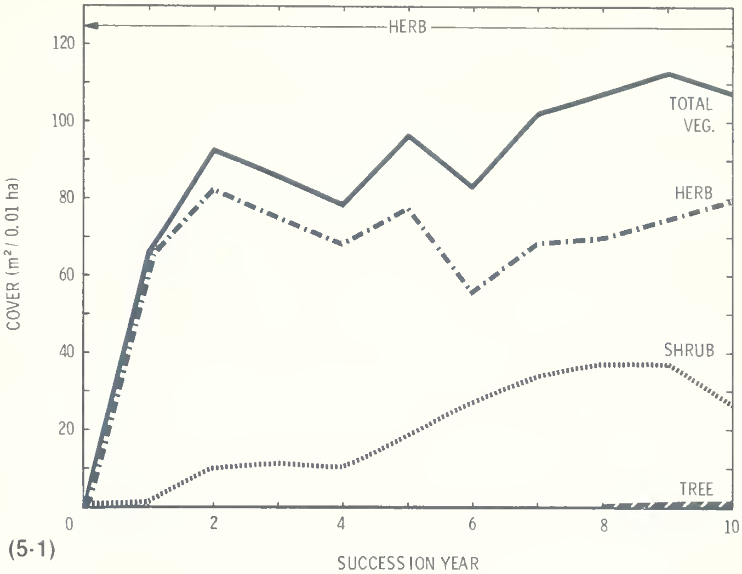


Figure 4.—Vegetation development for the extended herb stage sequence, 1967-77 (study area SD-05). Numerals designate the number of growing seasons since burning.



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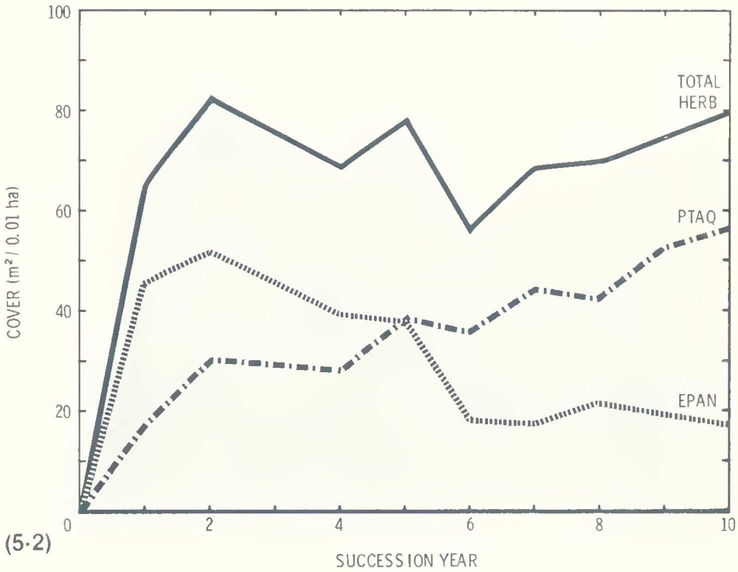

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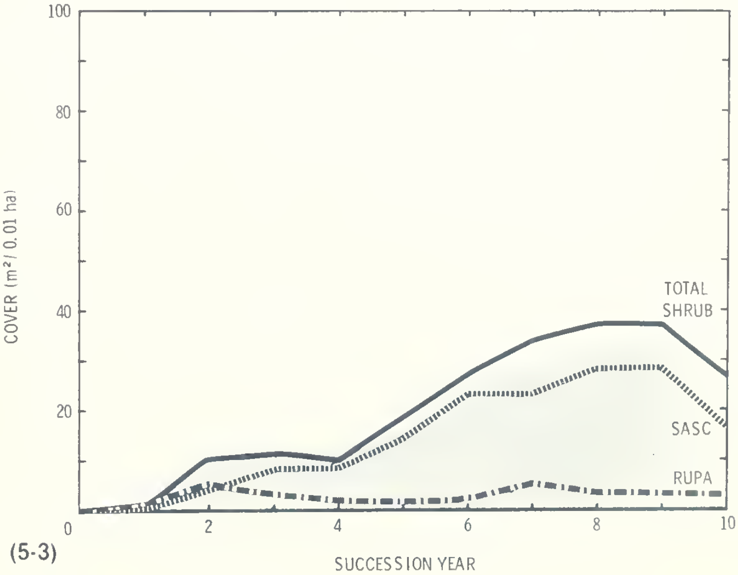


(5-3)

Figure 5.—Extended herb stage succession sequence (Study area SD-05): (5-1) development of plant cover and life-form components; (5-2) major herb component species: *Epilobium angustifolium* (EPAN) and *Pteridium aquilinum* (PTAQ); (5-3) major shrub component species: *Rubus parviflorus* (RUPA) and *Salix scouleriana* (SASC). Shaded areas denote the amount of cover contributed by the two principal species of each life-form component.

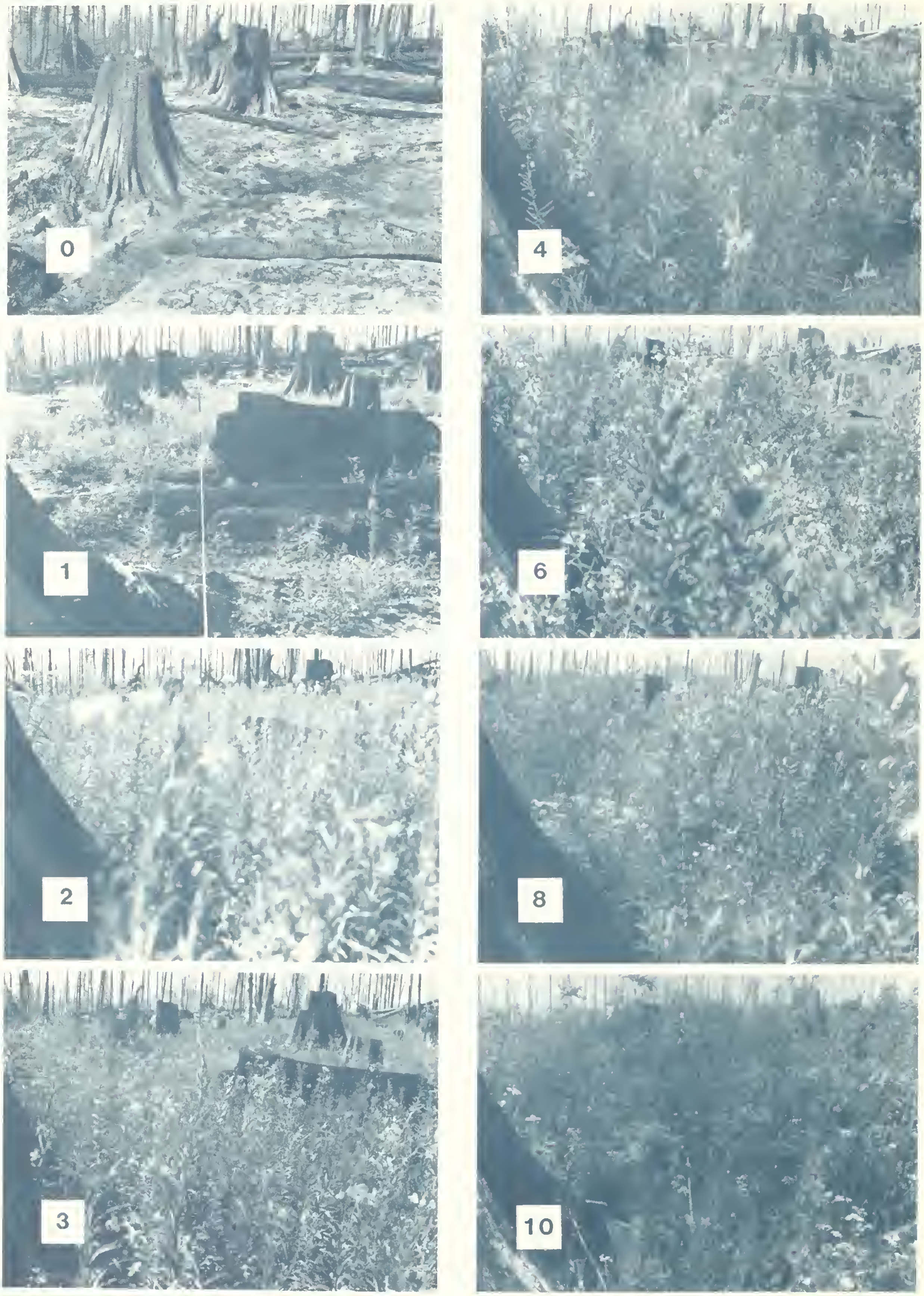


Figure 6.—Vegetation development for the medium-duration herb stage sequence, 1967-77 (Study area SD-07). Numerals designate the number of growing seasons since burning.

Medium-Duration Herb Stage Sequence.—A succession pattern with the herb stage of intermediate duration occurred on six study areas where shrub development surpassed herbs in the latter half of the decade (fig. 6). Major herb and shrub components were similar to those represented in the extended herb sequence except for the abundant presence of bracken fern. As with extended herb sequence, a tree component was poorly represented. Study area SD-07 characterized this pattern (fig. 7-1). Fireweed was responsible for the rapid initial development of the seral vegetation. Absence of associated abundant herb species following the early peak of fireweed's cover development in the second year resulted in a substantial decline in vegetative coverage (figs. 7-1, 7-2). The establishment and development of pearly-everlasting, a secondary offsite colonizer, was insufficient to compensate for the decline in fireweed in maintaining herb cover as bracken fern had done in the extended herb stage (fig. 7-2). The development of Scouler willow seedlings was primarily responsible for the increase in vegetative cover and succession to the shrub stage by the eighth year (figs. 7-1, 7-3). The shrub components for the extended and medium-duration herb stage patterns were quite similar in their composition and development.

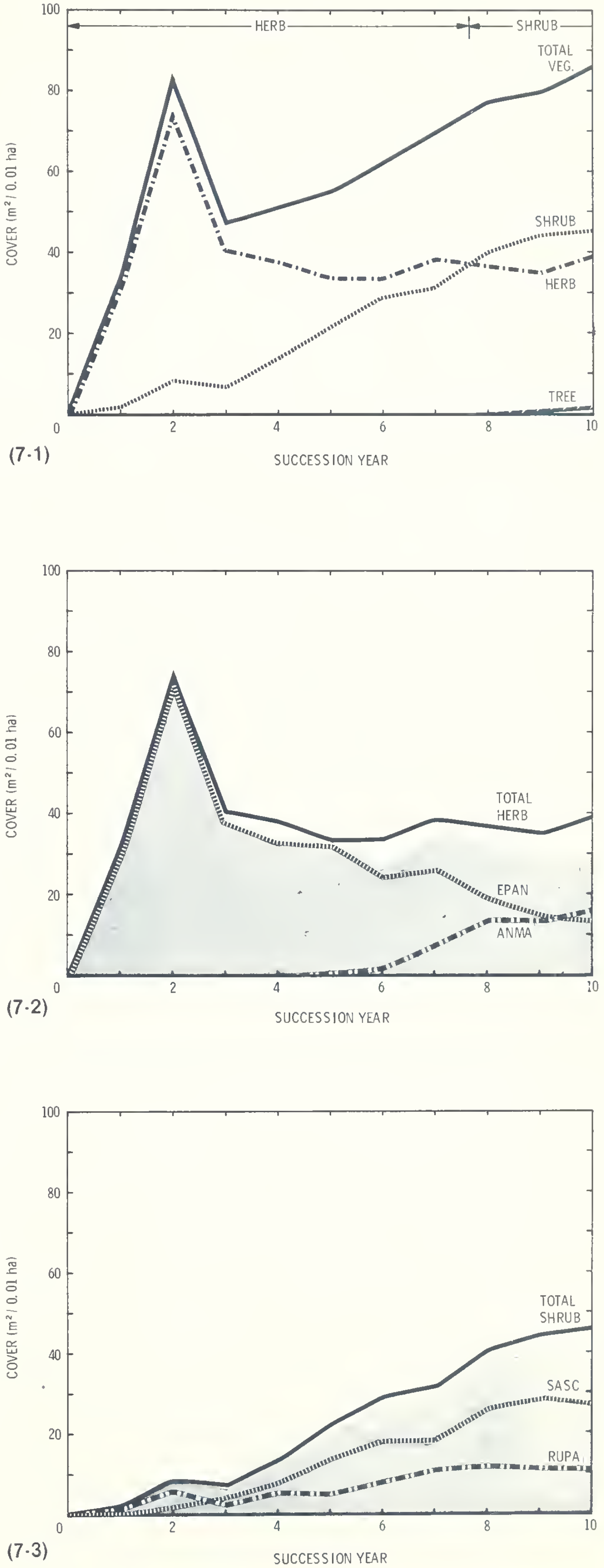


Figure 7.—Medium-duration herb stage sequence (Study area SD-07): (7-1) development of plant cover and life-form components; (7-2) major herb component species: *Anaphalis margaritacea* (ANMA) and *Epilobium angustifolium* (EPAN); (7-3) major shrub component species: *Rubus parviflorus* (RUPA) and *Salix scouleriana* (SASC). Shaded area denotes the cover contributed by the two principal species of each life-form component.

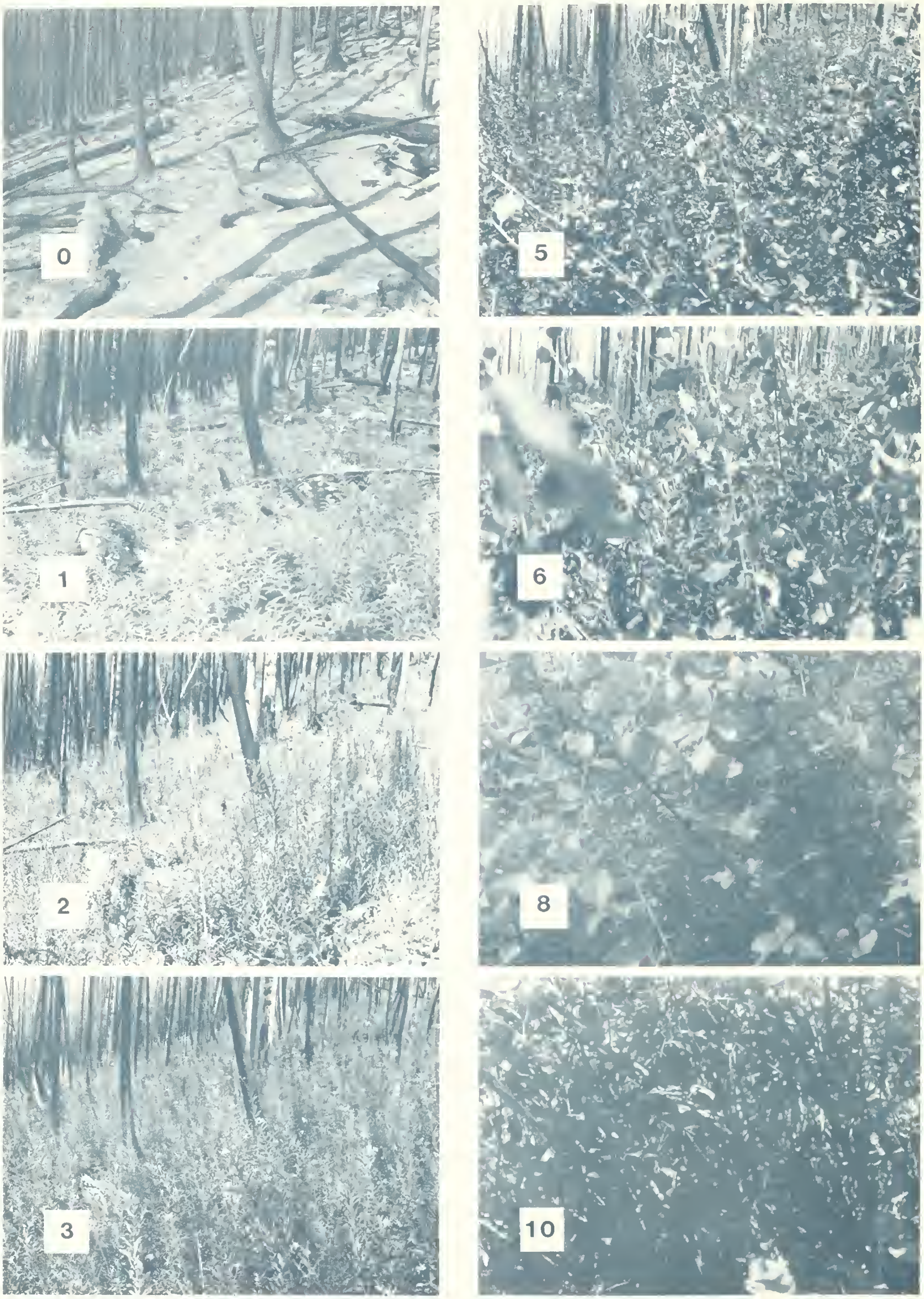
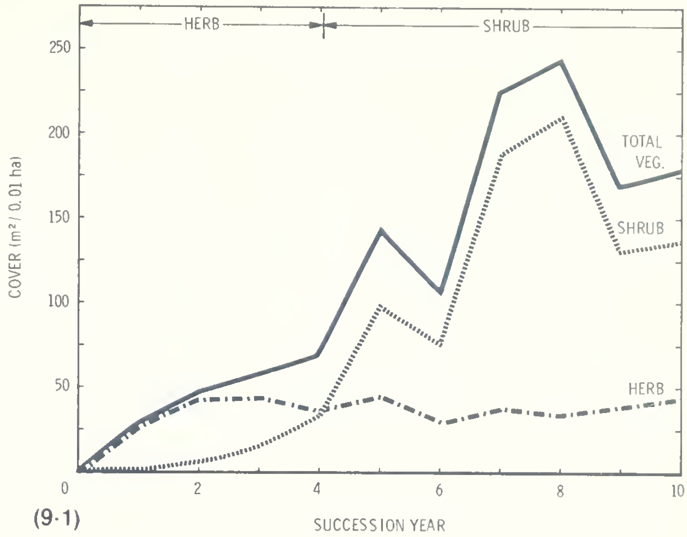


Figure 8.—Vegetation development for the short-duration herb stage sequence, 1967-77 (Study area SD-14). Numerals designate the number of growing seasons since burning.

Short-Duration Herb Stage Sequence.—Herb stage duration is shortened when the initial community contains an abundant shrub component of rapid-growing colonizer species. Five study areas showed a development sequence where shrub coverage exceeded that for herbs by mid-decade (fig. 8). Study area SD-14 provided the best example of the successional sequence associated with the development of a rapid-growing colonizer shrub species (fig. 9-1). Composition and relative development of the abundant species of the herb component were similar to those of the extended herb stage (fig. 9-2), as were the absence of a tree component and the presence of Scouler willow seedlings. However, composition of the shrub component differed markedly with the abundant presence of redstem seedlings. Relative to Scouler willow, development of redstem shrubs from seedlings was quite rapid. Following a short period of establishment, redstem rapidly increased its coverage through the eighth year and remained the dominant shrub through the end of the decade (fig. 9-3). Primarily as the result of redstem's development, the duration of the herb stage was reduced to 4 years. On several other study areas in this group the presence of minor components of survivor shrubs in addition to the seedling redstem served to shorten herb stage duration still further.



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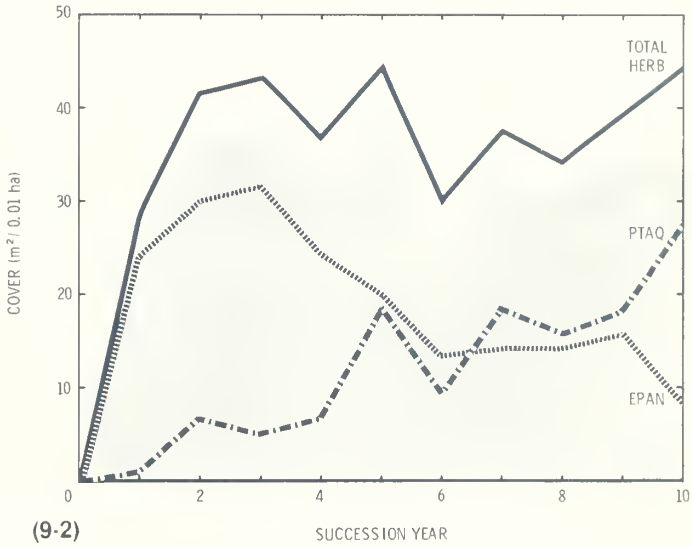

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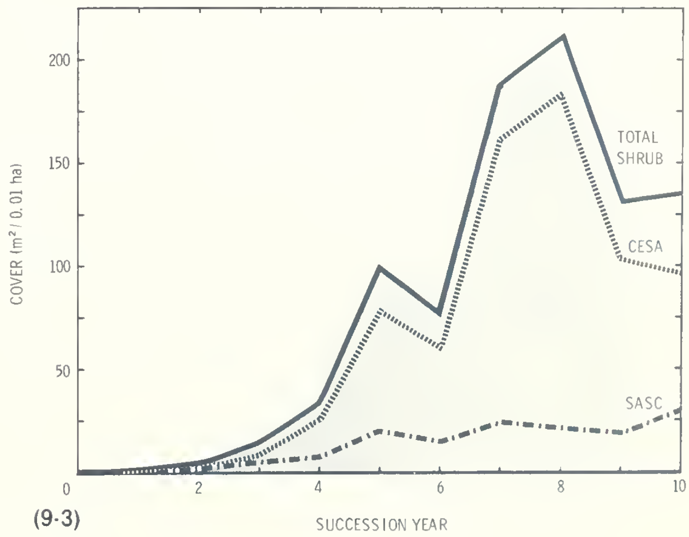


(9-3)

Figure 9.—Short-duration herb stage sequence (Study area SD-14): (9-1) development of plant cover and life-form components; (9-2) major herb component species: *Epilobium angustifolium* (EPAN) and *Pteridium aquilinum* (PTAQ); (9-3) major shrub component species: *Ceanothus sanguineus* (CESA) and *Salix scouleriana* (SASC). Shaded area denotes the amount of cover contributed by the two principal species of each life-form component.

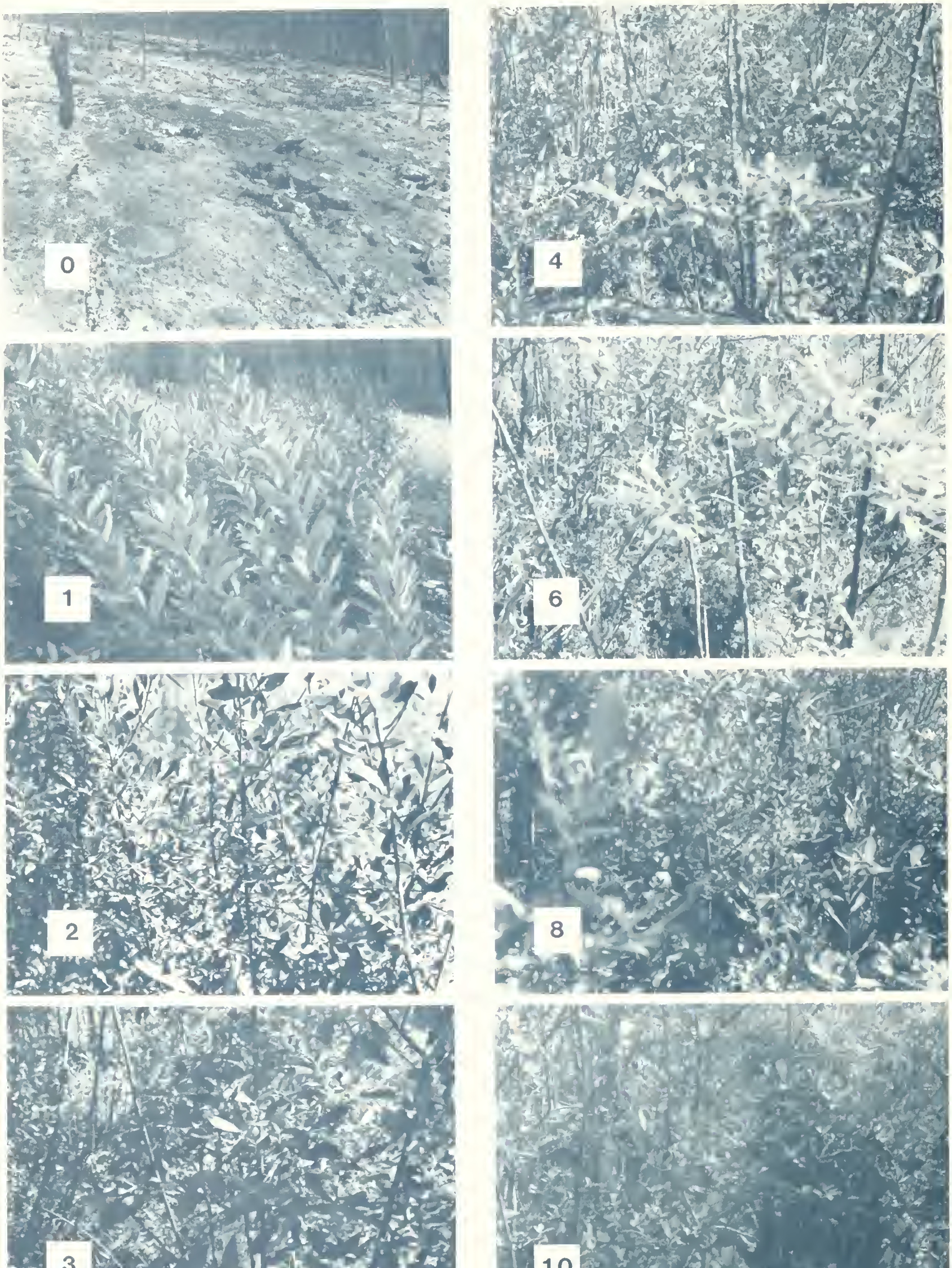
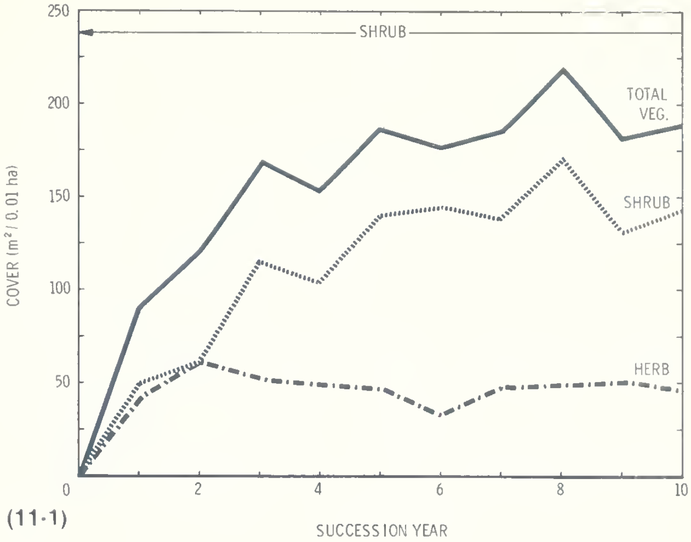


Figure 10.—Vegetation development for the initial shrub stage sequence, 1967-77 (Study area SD-17). Numerals designate the number of growing seasons since burning.

Initial Shrub Stage Sequence.—The initial herb stage can be eliminated when an abundant survivor component of shade-intolerant shrubs is present; with their rapid resprouting forest succession, in effect, begins at the shrub stage. Three study areas that were brushfields prior to the Sundance Fire developed shrub coverages that exceeded the herb component in the first year and remained so throughout the decade (fig. 10). This pattern was associated with an abundant presence of survivor herb and shrub components and a poorly represented or absent tree component. Postfire composition remained essentially that of the prefire community. Study area SD-17 represents this type of succession pattern (fig. 11-1). Rapid initial development of the herb component was due to the regrowth of pinegrass and lupine, both well-distributed survivor species (fig. 11-2). Regrowth from well-developed surviving Scouler willow root crowns largely accounted for the initial rapid increase in shrub cover during the first 3 years (fig. 11-3). Further development of shrub and vegetative cover resulted mainly from the slower regrowth of eight associated survivor shrub species, among which redstem was the most abundant. The cover development of redstem illustrated in figure 11-3 represents a combination of survivor resprouts and colonizer seedlings.



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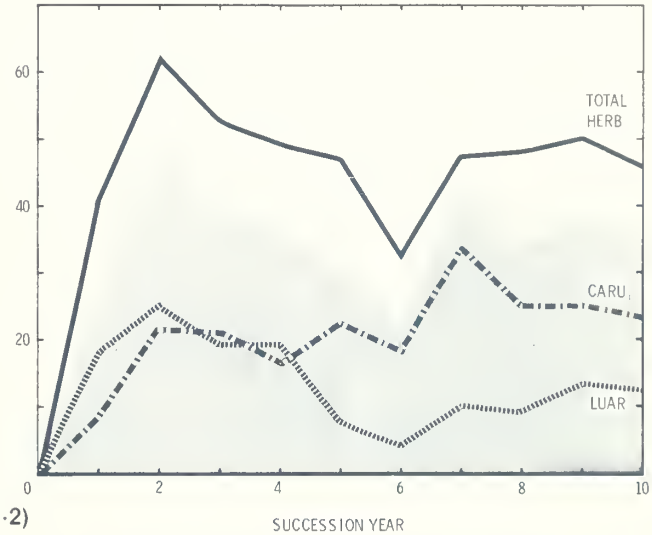

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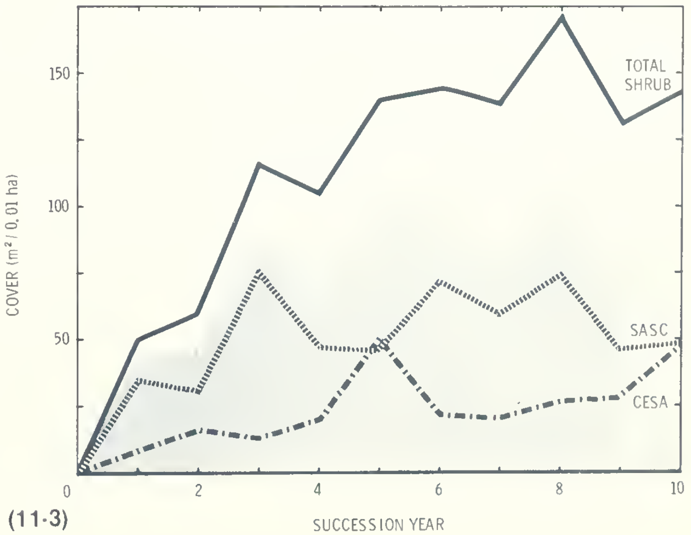


(11·3)

Figure 11.—Initial shrub stage sequence (Study area SD-17): (11-1) development of plant cover and life-form components; (11-2) major herb component species: *Calamagrostis rubescens* (CARU) and *Lupinus argenteus* (LUAR); (11-3) major shrub component species: *Ceanothus sanguineus* (CESA) and *Salix scouleriana* (SASC). Shaded area denotes the amount of cover contributed by the two principal species of each life-form component.

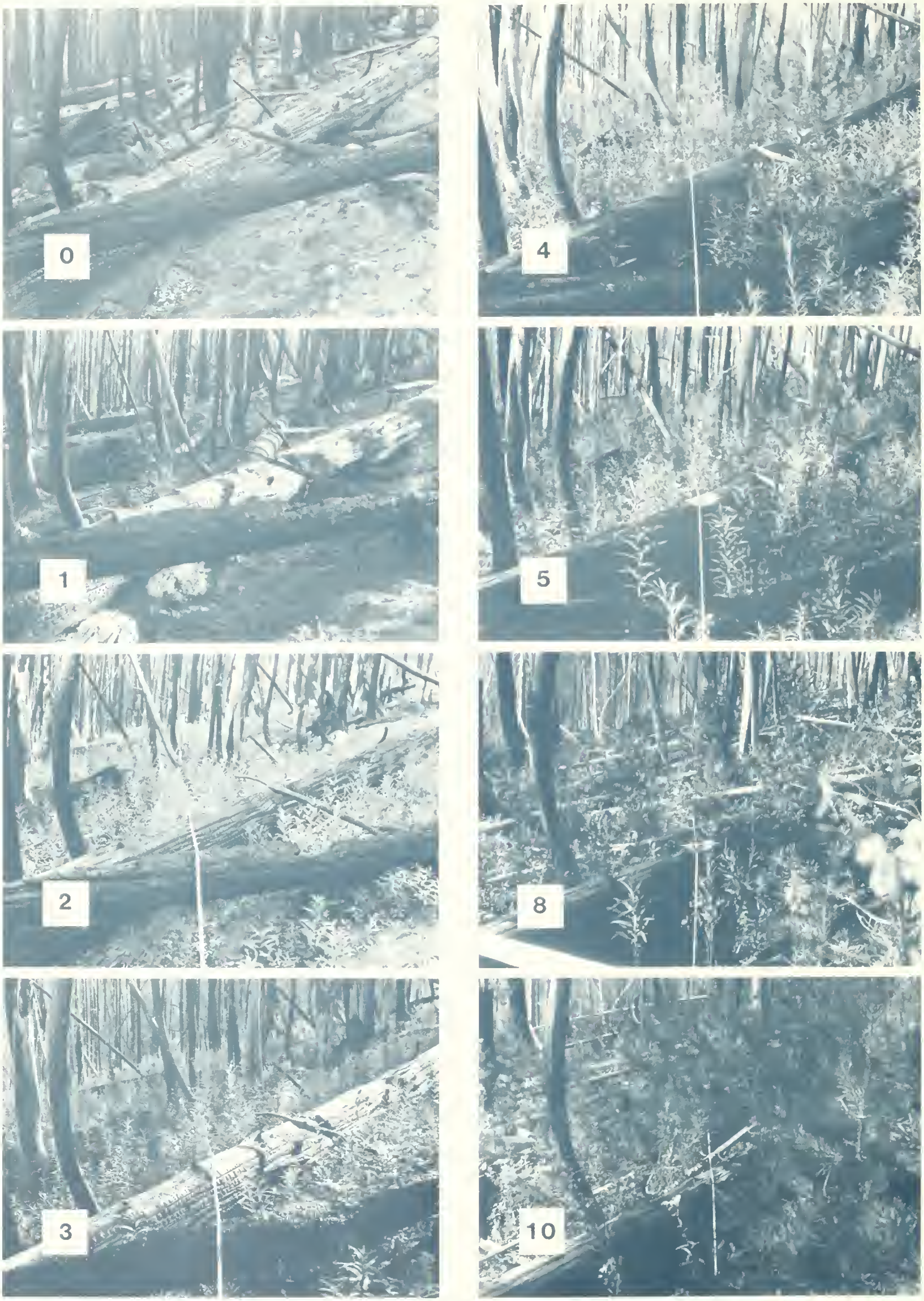
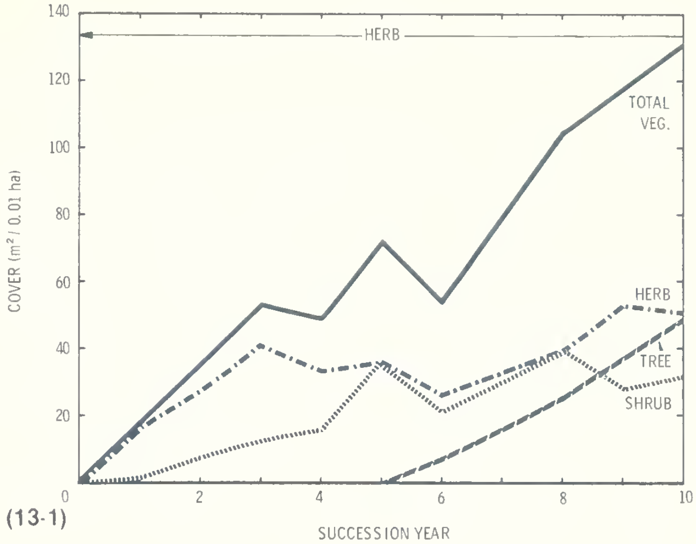


Figure 12.—Vegetation development for the herb-tree stage sequence, 1967-77 (Study area SD-19). Numerals designate the number of growing seasons since burning.

Herb-Tree Stage Sequence.—Trees generally were poorly represented, and their development on all but two sites did not exceed 10 percent cover. In the first decade no site developed a tree stage. However, the two sites with a well-distributed tree component have the potential of progressing to a tree stage in the second decade (fig. 12). Study area SD-19 had a well-represented coniferous tree component of an abundant population of seedling lodgepole pine. As an onsite colonizer, lodgepole pine seedlings established in the first year of succession along with seedlings of fireweed and Scouler willow, both from offsite sources, to form a major colonizer component in the initial community. The development of this combination of seral herb, shrub, and tree species is presented in figure 13-1. In addition to fireweed, bracken fern was well represented as a survivor in the herb component. The general pattern of development for these two herb species is similar to that for the extended and short-duration herb stages (figs. 13-2, 5-2). Development of the shrub component largely resulted from the growth of Scouler willow seedlings and the regrowth from several surviving root crowns of Sitka alder (fig. 13-3). The development of seedling willow in association with a dense stand of lodgepole pine and continued increase in bracken fern appears to preclude the occurrence of an intervening shrub stage between the herb and eventual tree stages (fig. 13-1).



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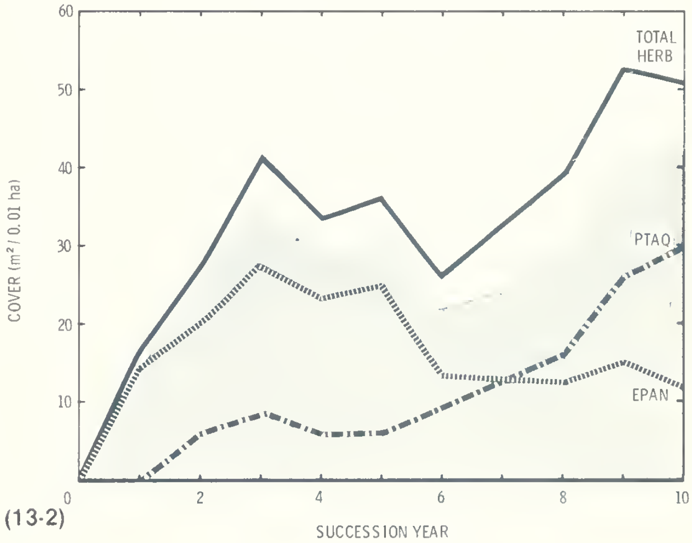

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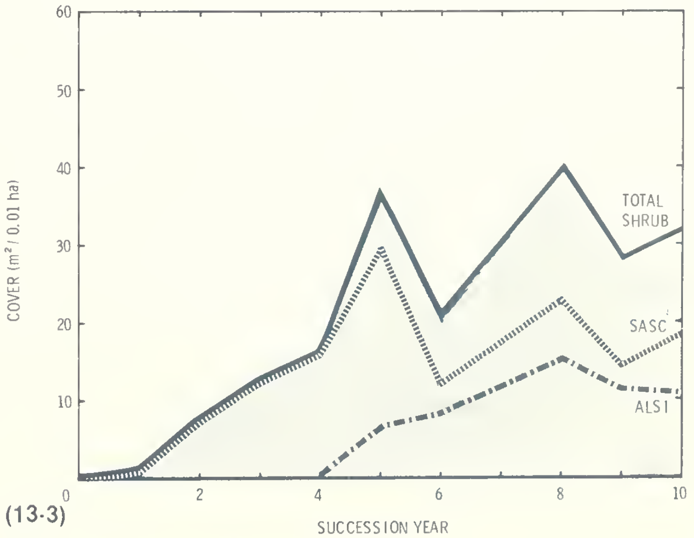

(13-3)

Figure 13.—Herb-tree stage sequence (Study area SD-19): (13-1) development of plant cover and life-form components; (13-2) major herb component species: *Epilobium angustifolium* (EPAN) and *Pteridium aquilinum* (PTAQ); (13-3) major shrub component species: *Alnus sinuata* (ALSI) and *Salix scouleriana* (SASC). Shaded areas denote the amount of cover contributed by the two principal species of each life-form component.

DISCUSSION

The term succession, applied to the development of forest vegetation, implies change. Both compositional change and structural change were evident in the secondary forest succession of Sundance Burn communities.

Compositional Change

Changes in vegetation over the first decade of succession involved amount more than kind of species. Compositional changes included about 40 percent of the seral flora. Of the 103 species recorded in the first year, 84 were still present in the 10th year. The addition of 36 species and the loss of 19 brought the seral floristic composition in the 10th year to 120 species. The average net increase was nearly two species per year.

However, the addition and loss of 55 species scarcely affected the character and abundance of seral vegetation. By the end of the first decade, only two of the herb species added to the initial flora, paintbrush and hawkweed, exhibited the development pattern of a potentially important secondary offsite colonizer. Both species displayed continuous increases in distributional occurrence (at least 30 percent frequency) and abundance (cover exceeded 1 percent) (table 6). Their low stature would appear to preclude the potential to dominate later phases of the herb stage. Nearly half of the additions to the seral flora have the potential to increase abundance in later seral stages, but present levels of occurrence for most of these species (including the climaxlike tree species western redcedar [*Thuja plicata* Donn ex D. Don] and western hemlock) are so infrequent as to remain undetected by any sample parameter other than presence. Thus, changes in floristic composition resulting from secondary offsite colonization have not affected the overall character of the seral vegetation of the first decade and appear to offer little potential for altering it in the second.

The principal changes in early seral vegetation largely reflect the development of the more important members of the initial postfire community. Most prominent among these over the burn generally were the perennial herbs fireweed and bracken fern and the shrubs redstem and Scouler willow. In addition, the perennial herbs pinegrass and lupine, the shrubs western serviceberry, pachistima, and thimbleberry, and the pioneer tree species paper birch and lodgepole pine constituted important local elements of the seral vegetation on one to several study areas.

The trend for these species has been increasing abundance, with many attaining a maximum or more or less stable level of cover development during the first 10 years of succession. Fireweed was the only major seral species to show a marked, continuous decline after attaining peak coverages early in the decade. This decline occurred in both the absence and the presence of other major seral species such as bracken fern and redstem. Bracken fern appears to be the exception among the important early seral herb species by continuing to increase its coverage throughout the decade even as an understory species in dense shrub stands. As would be expected from their slower development rate and longer maturation time, both paper birch and lodgepole pine continued to increase their coverage through the end of the decade.

Structural Change

Early accounts of forest succession in the Northern Rocky Mountains used elements of both composition and structure in describing developmental changes. However, differences in structural characteristics were readily perceived and have been more extensively employed in identifying stages of sequential development. The structural changes used for the early stages most often reflected changes in the dominant life form. In later stages, changes in size and height of the tree component were used.

In characterizing the succession perceived for the forests of northern Idaho, both Leiberg (1897, 1899) and Larsen (1929) included several stages that preceded the overtopping of the subordinate vegetation by trees. Their initial period was represented by establishment of pioneer plants, followed by maturation of perennial herbs and shrubs. Results from the Sundance Burn study support this general representation of forest succession but differ in that (1) the initial postfire community contained both pioneer and climaxlike species derived from survivor and colonizer origins, and (2) the differential development of the herb and shrub life forms was the defining feature of the pretree stages.

Prior to the development of vascular vegetation, an early seral stage noted by Leiberg (1899) and Humphrey and Weaver (1915) included ground surface bryophytes such as firemoss or liverwort. A well-developed ground surface bryophyte layer occurred extensively on the Sundance Burn. However, it did not appear as a distinct initial stage but developed concurrently with the herb

Table 6.—Development of secondary colonizer species exhibiting progressive increases in frequency and cover throughout the first decade

Species	Initial appearance SY[1]	Maximum increase in frequency SY[1]	%	Maximum increase in cover SY[1]	%
Castilleja miniata	3-10	6-10	5-35	10	2
Hieracium albiflorum	2-7	6-10	5-95	9-10	1-5

[1]Succession year; designates the number of years (growing seasons) since the fire.

stage. The bryophyte surface layer, composed of ground mosses such as firemoss or similar pioneer species but without liverworts, occurred on all study areas. Patches of a ground moss layer were evident in the first year and increased rapidly in coverage over the next several years. Because vascular vegetation was given priority over bryophytes in making coverage estimates, actual cover values for moss are not available. But by the third year on most of the mesic sites, the moss layer covered all of the available ground surface not physically occupied by vascular plants or woody debris. Throughout the decade it has continued to maintain high coverages even under the shade of dense stands of pioneer herbs and shrubs. In shaded microsites beginning about the third or fourth year, larger mosses such as *Polytrichum juniperinum* Hedw. became evident and more abundant, locally replacing the smaller mosses. In sunny, exposed sites, however, this replacement did not take place. These apparent changes suggest that a successional process is operating at the bryophyte level on the ground surface and in conjunction with development of the vascular vegetation. Later in the decade, some deterioration of the ground bryophyte layer has been observed. This situation was restricted to accumulations of slower decomposing litter debris, notably from bracken fern and large, charred bark flakes from fire-killed trees and occasionally from local concentrations of redstem litter sufficient to completely bury the moss. The litter produced by most of the early seral vegetation did not produce a sufficiently persistent accumulation to eliminate the ground bryophyte layer. It appears that the destruction of this layer will be related to the build-up of coniferous foliage and twig litter sufficient to exclude light from the ground surface.

Leiberg's (1897, 1899) observations on the establishment of fireweed and the pioneer species of willow and *Ceanothus* in the initial stage that became prominent in early succession are substantiated by the results of Lyon's (1971) work and the present study. No evidence was found, however, to support Leiberg's contention that the accumulation of humus derived from the litter of early pioneer deciduous shrubs and herbaceous plants was essential for the germination of coniferous tree seed. On the study area that developed a dense stand of pioneer conifers, newly germinated tree seedlings were observed only in the first year. These trees became established on an exposed, ash-bed surface in the year following the fire. The relative absence of conifer seedlings in the first and subsequent years for many of the Sundance Burn study areas represents a successional situation Leiberg (1897) described as "second burns." This was attributed to the lack of onsite seed sources for tree species that resulted from the reburning of coniferous forest stands prior to the time trees had reached abundant cone-bearing size.

Larsen's (1929) descriptive sequence for subordinate vegetation included a second stage that preceded the first tree stage. The second stage was characterized by perennial plants, mostly shrubs, with berries or berrylike fruit. For the Sundance Burn the berry-fruited species represented 16 percent of the seral flora. The majority of these species derived from survivor origins and were slow to develop (less than 5 percent cover during the first decade). Collectively, berry-fruited plants contributed little to the seral vegetative cover of the Sundance Burn, but two shrub species, western serviceberry and thimbleberry, did constitute substantial amounts of cover on a few study areas. In these instances their relative contribution to shrub cover was greater during the initial herb stage. Though coverages of these two species continued to increase in the shrub stage, their proportionate representation generally declined. Of all of the berry species present, thimbleberry—with its broad leaves, relatively wide distribution among study areas, and potential for local expansion by rhizome growth—offers the greatest potential to fit Larsen's descriptive stage, but such an occurrence has yet to develop on the areas under study.

Of the earlier representations of succession in northern Idaho, Daubenmire and Daubenmire (1968) most closely agree with the results of this study. With about 40 percent of the total floristic composition for the decade originating from offsite sources and a significant part of the seral vegetation attributable to fireweed and Scouler willow, the successional development indeed fits the Daubenmires' (1968) initial or "invasion" stage. But because most of the important offsite-origin seral species became established on sites unoccupied by surviving vegetation, the term "colonization" more appropriately describes the process involved. Rather than an invasion, with aggressive displacement of established species, the process appears to be passive in that initial colonizers use unoccupied sites created by fire disturbance. Secondary colonizers differ in this respect, for they must be tolerant of site modification and competition from established seral vegetation.

Sequence and Duration of Early Stages

For the first decade of secondary forest succession, the 18 Sundance Burn study areas provide examples of both two-stage (initial herb to shrub stage) and one-stage patterns. One-stage patterns were evident on sites where the lack or abundance of shrubs resulted in either an initial herb stage or an initial shrub stage that remained dominant throughout the decade. On 15 study areas, the successional sequence began with the herb stage. By the end of the first decade, 11 study areas had developed to a shrub stage but none had reached a tree stage. The sequential relationship between the development of the three life-form groups is most apparent when pioneer colonizer species of each life-form group establish in the first year. For the early phases of secondary succession on the Sundance Burn, the concurrent development of the three life-form components proceeding at different rates appears to be the principal successional process operating.

For most study areas where succession began with an herb stage, the rapid development of the herb component was due to the abundant presence of fireweed. Results from the Sundance Burn indicate that the duration of each stage was dependent largely on the composition and abundance of the species already established for

the next higher order life form. For example, the slower rate of cover development for bracken fern was responsible for extending the duration of a dominant herb stage into the latter half of the first decade on sites where shrub development was minimal or slow. For most study areas durations for the herb stage were directly related to the composition and growth form of the principal members of the shrub component.

For those study sites exhibiting a two-stage sequence in which the shrub stage began in the first half of the decade, the seedling form of redstem was the major shrub component. Where the shrub stage began in the latter half of the decade, the seedling form of Scouler willow was the major shrub component. On sites where survivor shrubs made up an increasingly larger proportion of the shrub component, the duration of the herb stage was correspondingly shortened. When mature Scouler willow constituted a major portion of the survivor shrub component, its rapid regrowth was largely responsible for the exclusion of an initial herb stage. Thus, the spectrum of succession patterns identified from the Sundance Burn varied in the duration of the dominant life-form stage rather than in sequential order. The sequence of dominant life-form stages was consistent with the modal pattern (herb-shrub-tree) historically used for representing secondary succession of Northern Rocky Mountain coniferous forests.

CONCLUSIONS

All of the species important to the early development of seral vegetation on the Sundance Burn were present in the first year of succession. Species composing the initial postfire vegetation derived from three origins: survivor, residual colonizer, and initial offsite colonizer. Survivors constituted the largest group of first-year species and represented more important seral species than any other group. Major survivor species included bracken fern, Scouler willow, thimbleberry, pinegrass, lupine, western serviceberry, and paper birch. Residual colonizers constituted the smallest group of first-year species but included two of the most important early seral species, redstem and lodgepole pine. Initial offsite colonizers of major importance were fireweed and Scouler willow. During the first decade no major seral species originated from the secondary offsite colonizer group.

Most of the prominent early seral species exhibited a cover development pattern during the first decade that tends to level off following the initial period of increase. Fireweed was the only prominent seral species with an unequivocal peaking out (increase-decrease) pattern within the first decade. Redstem may have similarly peaked in development in the first decade, but with maximum coverages occurring later in the decade the permanancy of this trend is not clear. The development pattern for bracken fern and lodgepole pine, in contrast to the other major seral species, continued to increase in cover throughout the decade.

In this study, examples of colonizer-dominated seral vegetation were most often associated with formerly well-developed forested sites. On such sites the survivor component was usually poorly represented or absent. At the other end of the seral development spectrum, seral vegetation developing on prefire brushfields and formerly open (lightly shaded) forest sites was usually dominated by survivors. Thus, even with the severe fire treatment of the Sundance Fire, the composition of the prefire vegetation directly influenced the presence and composition of the postfire survivor component, and this in turn influences the suitability of the site for colonizers. Given the knowledge of the prefire composition, the species composition of the postfire survivor component is largely predictable. Probable composition of onsite colonizers may also determine if past seral and current stand history are known, or if adjacent seral examples are available. Composition of the postfire offsite colonizer component is the most uncertain element due to the chance nature of the immigration event. But even here a knowledge of the regularity of seed or fruit production and the regional suitability of burned sites for seedling establishment could do much to reduce the uncertainty of the presence of prominent seral species such as fireweed.

Changes in floristic composition (species gained and lost) over the first 10 years demonstrated little effect on the course or development of seral vegetation. No evidence supported the "relay floristics" concept of vegetation development (Egler 1954; Drury and Nisbet 1973) whereby initial or preceding dominant species modify the site to their own exclusion, thereby preparing it for replacement by succeeding species. Rather, results from this study suggest that the preponderant successional process operating during the first decade of the Sundance Burn succession was one of differential development of species forming the initial community. Supporting this view is the sequential development of herb and shrub stages dominated by pioneer colonizer species established at the start of succession (such as fireweed-redstem succession on SD-14 or fireweed-Scouler willow succession on SD-07).

A degree of autogenic modification of the ground surface has occurred from shading and litter deposition by the developing seral vegetation. In the first decade, the influence of these modifications appears to be reflected more in the tolerance of established species to changes in the near-surface environment than to preparing the site to accommodate the establishment of more climax-like species. Up to this time, short-lived obligate pioneer and exotic ruderal species (such as geranium, cudweed, and rye) appear to have been the most affected. The establishment and dispersal of paintbrush between the third and ninth years may be an example of the effect of the autogenic modification process in facilitating the establishment of a secondary colonizer species. As succession proceeds to later stages, with development of the coniferous component and its associated formation of a coniferous organic mantle, this process should become more pronounced and important.

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APPENDIX: SERAL CHARACTERISTICS OF THE FLORISTIC COMPOSITION OF THE FIRST DECADE'S SECONDARY SUCCESSION ON SUNDANCE BURN STUDY AREAS.

Species	Physiognomic life form	Seral origin	Fire survival adaptation	First/last S.Y. record	Occurrence Pres	Occurrence Freq	Occurrence Cover
Abies grandis	Tree	Introduced		2	6	4	3
Acer glabrum	T-Shrub	Survivor	Root crown	1	12	2	4
Achillea millefolium	Herb	Survivor	Rhizome	1	11	2	1
Adenocaulon bicolor	Herb	Survivor	Caudex	1	3	1	
Agoseris grandiflora[a]	Herb	2d O-S colonizer		9	4	1	
Agrostis alba[b]	Herb	Introduced		1	12	7	3
Agrostis exarata	Herb	2d O-S colonizer		5	2	1	
Agrostis scabra	Herb	I O-S colonizer(?)		1	9	1	
ALNUS SINUATA	T-Shrub	Survivor	Root crown	1	10	8	6
Alopecurus pratensis[b]	Herb	2d O-S colonizer		9	1		
AMELANCHIER ALNIFOLIA[c]	T-Shrub	Survivor	Root crown	1	14	12	4
ANAPHALIS MARGARITACEA	Herb	I O-S colonizer		1	18	17	13
Antennaria microphylla	Herb	2d O-S colonizer		3	3		
Antennaria neglecta	Herb	2d O-S colonizer		9	1	1	
Apocynum androsaemifolium[a]	Herb	Survivor	Rhizome	1	12	9	4
Arabis holboellii	B-Herb	R-colonizer	GSS-1	1	3	1	
Aralia nudicaulis[c]	Herb	Survivor	Rhizome	1	2	2	2
Arnica cordifolia	Herb	Survivor	Rhizome	1	2	1	
Arnica latifolia	Herb	Survivor	Rhizome	1	2	2	1
Asarum caudatum	Herb	R-colonizer	GSS-1	1	2	1	
Aster conspicuus	Herb	Survivor	Rhizome	1	6		
Aster engelmannii	Herb	Survivor	Caudex	1	4	1	
Aster laevis	Herb	2d O-S colonizer		3/4	1		
Athyrium filix-femina	Herb	Survivor(A)		2	2		
Berberis repens[c]	LWP	Survivor	Rhizome	1	6	3	1
BETULA PAPYRIFERA	Tree	Survivor R-colonizer	Root crown CSS-1	1 1	8	5	2
Bromus inermis[b]	Herb	2d O-S colonizer		10	1		
CALAMAGROSTIS RUBESCENS	Herb	Survivor	Rhizome	1	10	7	4
Calochortus apiculatus	Herb	Survivor	Bulb	1	1	1	
Campanula rotundifolia	Herb	2d O-S colonizer		7	1		
Carex deweyana	Herb	R-colonizer	GSS(?)	1	1		
Carex geyeri	Herb	Survivor	Rhizome	1	2	2	1
Carex pachystachya	Herb	R-colonizer	GSS(?)	1	1	1	
Carex rossii	Herb	R-colonizer	GSS-2	1	17	12	10
Castilleja miniata	Herb	2d O-S colonizer		3	12	5	1
CEANOTHUS SANGUINEUS	T-Shrub	Survivor R-colonizer	Root crown GSS-2	1 1	14	12	10
Ceanothus velutinus	Shrub	Survivor R-colonizer	Root crown GSS-2	1 1	6	3	4
Chenopodium album[b]	A-Herb	Introduced(A)		1/1	1		
Chimaphila umbellata	Herb	Survivor(A)		3	2		
Cirsium arvense[b] [a]	Herb	Survivor	Rhizome	1	4	1	1
Cirsium vulgare[b] [a]	B-Herb	I O-S colonizer		1	12	7	
Clintonia uniflora[c]	Herb	Survivor	Rhizome	1	17	8	3
Collinsia parviflora	A-Herb	R-colonizer	GSS-1	1	3	3	
Conyza canadensis	A-Herb	I O-S colonizer		1	17	10	
Cryptantha affinis	A-Herb	R-colonizer	GSS-1	1	2	2	1
Dactylis glomerata[b]	Herb	Introduced		1	9	4	3
Deschampsia elongata	Herb	2d O-S colonizer		6	3		
Disporum hookeri[c]	Herb	Survivor	Rhizome	1	17	12	3
Dracocephalum parviflorum	B-Herb	R-colonizer	GSS-2	1/1	2		
EPILOBIUM ANGUSTIFOLIUM[a]	Herb	I O-S colonizer Survivor	 Rhizomelike root	1 1	18	18	18
Epilobium paniculatum[a]	A-Herb	I O-S colonizer		1	13	8	
Epilobium watsonii[a]	Herb	I O-S colonizer		1/6	16	9	
Equisetum arvense	Herb	Survivor	Rhizome	1	1		
Erigeron acris	B-Herb	2d O-S colonizer		6	6	4	
Erucastrum gallicum[b]	A-Herb	Introduced(A)		1/1	1		

(con.)

APPENDIX. (Con.)

Species	Physiognomic life form	Seral origin	Fire survival adaptation	First/last S.Y. record	Occurrence Pres	Freq	Cover
Festuca arundinacea[b]	Herb	Introduced		1	16	12	4
Festuca occidentalis	Herb	2d O-S colonizer		3	3	1	
Filago arvensis[b]	A-Herb	I O-S colonizer		1	9	2	
Fragaria vesca[c]	Herb	Survivor	Caudex	1	4	1	1
Galium triflorum[d]	Herb	R-colonizer	GSS-1	1	5	2	
Geranium bicknellii	A-Herb	R-colonizer	GSS-2	1/9	5	4	3
Gnaphalium microcephalum	B-Herb	I O-S colonizer		1	18	12	1
Gnaphalium palustre	A-Herb	I O-S colonizer		1/5	7		
Gnaphalium viscosum	B-Herb	2d O-S colonizer		3	13	9	
Gymnocarpium dryopteris	Herb	Survivor(A)		3	2		
Habenaria elegans	Herb	Survivor	Tuber	1	15	4	
Heuchera cylindrica	Herb	Survivor(?)		4	1		
Hieracium albiflorum	Herb	2d O-S colonizer		2	18	15	6
Hieracium umbellatum	Herb	2d O-S colonizer		9	1		
Holodiscus discolor	Shrub	Survivor	Root crown	1	6	3	3
Hypericum perforatum[b]	Herb	2d O-S colonizer		4/9	1		
Iliamna rivularis	Herb	Survivor	Caudex	1	12	8	5
		R-colonizer	GSS-2	1			
Juniperus communis[c]	Shrub	2d O-S colonizer		5	1	1	
Lactuca serriola[b,a]	A-Herb	I O-S colonizer		1/1	5		
Larix occidentalis	Tree	R-/I O-S colonizer(?)		10	4		
Lilium columbianum	Herb	Survivor	Bulb	1	10	8	1
Lonicera utahensis[c]	Shrub	Survivor	Root crown	1	11	1	3
LUPINUS ARGENTEUS	Herb	Survivor	Caudex	1	3	3	3
Luzula parviflora	Herb	2d O-S colonizer		4	1		
Luzula piperi	Herb	Survivor(?)		1	1	1	
Oplopanax horridum[c]	Shrub	Survivor	Root crown(?)	1	1		
Osmorhiza chilensis[d]	Herb	2d O-S colonizer		5	1	1	
PACHISTIMA MYRSINITES	Shrub	Survivor	Root crown	1	18	17	13
		R-colonizer	GSS-1	1			
Phleum pratense[b]	Herb	Introduced		1	13	5	2
Picea engelmannii	Tree	Introduced		2	6	3	3
PINUS CONTORTA	Tree	R-colonizer	CSS-1 or 2	1	15	4	5
Pinus monticola	Tree	R-colonizer	CSS-1	1	13	2	1
Plantago major[b]	Herb	Introduced(A)		1	2		
Poa compressa[b]	Herb	2d O-S colonizer		9	1	1	
Poa palustris[b]	Herb	I O-S colonizer		1	3	1	
Polygonum douglasii	A-Herb	R-colonizer	GSS-1	1	2	2	
Polygonum lapathifolium[b]	A-Herb	Introduced(A)		1/1	1		
Populus tremuloides[a]	Tree	Survivor	Root crown	1	13	7	3
		I O-S colonizer		1			
Populus trichocarpa[a]	Tree	Survivor	Root crown	1	2	1	
		I O-S colonizer		1			
Prunus emarginata[c]	T-Shrub	Survivor	Root crown	1	5	3	3
Pseudotsuga menziesii	Tree	Introduced		1	18	12	9
PTERIDIUM AQUILINUM	Herb	Survivor	Rhizome	1	15	15	14
Pyrola asarifolia	Herb	Survivor	Rhizome	1	6	1	
Pyrola picta	Herb	Survivor	Rhizome	1	5	3	1
Pyrola secunda	Herb	Survivor	Rhizome	2	12	7	
Ribes lacustre[c]	Shrub	R-colonizer	GSS-2	1	4		
Ribes viscosissimum[c]	Shrub	R-colonizer	GSS-2	1	2	1	2
Rosa gymnocarpa[c]	Shrub	Survivor	Root crown	1	11	8	8
Rubus idaeus[c]	Shrub	2d O-S colonizer		4	5	1	1
Rubus leucodermis[c]	Shrub	Survivor	Root crown	1	7	6	4
		R-colonizer	GSS-2 (?)	1			
RUBUS PARVIFLORUS[c]	Shrub	Survivor	Rhizome	1	15	11	13
		R-colonizer	GSS-2	1			
Rumex acetosella[b]	Herb	Survivor	Rhizome	1/5	1		
SALIX SCOULERIANA[a]	T-Shrub	Survivor	Root crown	1	18	18	18
		I O-S colonizer		1			
Sambucus racemosa[c]	Shrub	Survivor	Root crown	1	5	4	3
		R-colonizer	GSS-2	1			

(con.)

APPENDIX. (Con.)

Species	Physiognomic life form	Seral origin	Fire survival adaptation	First/last S.Y. record	Occurrence Pres	Freq	Cover
Secale cereale[b]	A-Herb	Introduced		1/4	10	7	
Senecio vulgaris[b]	A-Herb	Introduced(A)		1/5	9	2	
Silene noctiflora[b]	A-Herb	Introduced(A)		1/3	2		
Smilacina racemosa[c]	Herb	Survivor	Rhizome	1	4	2	
Smilacina stellata[c]	Herb	Survivor	Rhizome	1	8	4	2
Solidago canadensis	Herb	Survivor	Rhizome	1	18	11	
Sorbus scopulina[c]	T-Shrub	Survivor	Root crown	1	4		
Spergularia rubra[b]	A-Herb	I O-S colonizer		1/2	6	1	
Spiraea betulifolia	Shrub	Survivor	Rhizome	1	8	7	5
Spiranthes romanzoffiana	Herb	2d O-S colonizer		3	1		
Stellaria media[b]	A-Herb	Introduced(A)		1/5	3	1	
Stellaria obtusa	Herb	R-/I O-S colonizer(?)		1/1	1		
Symphoricarpos albus[c]	Shrub	Survivor	Rhizome	1	4	3	4
Taraxacum laevigatum[b,a]	Herb	2d O-S colonizer		5/6	2		
Taraxacum officinale[b,a]	Herb	I O-S colonizer		1	13	9	
Thalictrum occidentale	Herb	Survivor	Rhizome	1	7	2	2
Thuja plicata	Tree	2d O-S colonizer		6	2		
Tiarella trifoliata	Herb	Survivor	Caudex	1	2	2	
Tragopogon dubius[b,a]	B-Herb	2d O-S colonizer		8	1		
Trautvetteria caroliniensis	Herb	Survivor	Rhizome	1	4	1	
Trifolium agrarium[b]	A-Herb	2d O-S colonizer(?)		2/6?	1		
Trifolium hybridum[b]	Herb	Introduced		1	10	4	2
Trifolium repens[b]	Herb	Introduced		1	12	7	2
Trillium ovatum	Herb	Survivor	Corm	1	2		
Trisetum cernuum	Herb	2d O-S colonizer		10	2		
Tsuga heterophylla	Tree	2d O-S colonizer		6	4		
Vaccinium membranaceum[c]	Shrub	Survivor	Rhizome	1	17	9	6
Viola glabella	Herb	Survivor	Rhiz/Caud	1	6	3	
		R-colonizer	GSS-1	1			
Viola orbiculata	Herb	Survivor	Rhizome	1	16	16	
		R-colonizer	GSS-1	1			
Xerophyllum tenax	Herb	Survivor	Rhizome	1	8	3	3

(TOTAL: 139 species)

LEGEND:

Species

Names in capital letters denote principal cover species. (15+ percent cover)
[a]seed or fruit capable of long-range wind dispersal
[b]exotic species
[c]berry or berrylike fruit bird and/or animal dispersed
[d]armed fruit animal dispersed

Physiognomic life form:

T-Shrub = tall shrub (maximum height >2 m)
LWP = low woody plant (maximum height <0.5 m)
A-Herb = annual herb
B-Herb = biennial or short-lived perennial herb

Seral origin:

Introduced denotes planted or seeded by man
R-colonizer denotes residual colonizer (onsite source)
I O-S colonizer denotes initial offsite colonizer (immigration in succession year 1)
2d O-S colonizer denotes secondary offsite colonizer (immigration after succession year 1)
Double entry in the species listing indicates those 14 species that exhibited more than one seral origin
(A) = accidental: denotes very infrequently surviving species or introduced as a "weed" seed in seeding mixture

Fire survival adaptation

CSS = Tree crown source seed (onsite): 1 short-term viability, 2 long-term viability
GSS = Ground source seed (onsite): 1 short-term viability, 2 long-term viability

First/last succession year (S.Y.) record: First and last year of recorded occurrence

Occurrence: Numerals denote the number of study areas on which the species occurred as presence, frequency, and cover, respectively

Stickney, Peter F. First decade plant succession following the Sundance Forest Fire, northern Idaho. General Technical Report INT-197. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1986. 26 p.

Describes the first 10 years of vegetation development following disturbance by a holocaustic forest fire in a western redcedar-western hemlock type in the Selkirk Range. Postfire development of vegetation is represented as life-form stages and predominant cover species. Differential development of plant species established in the first postfire year appears to be the principal process operating in the early seral phase of this secondary forest succession.

KEYWORDS: postfire succession, forest succession, early seral stages, wildfire succession, western redcedar type, western hemlock type, initial vegetation

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**Intermountain
Research Station**

General Technical
Report INT-198

July 1986

Prescribed Fire Opportunities in Grasslands Invaded by Douglas-fir: State-of-the-Art Guidelines

**George E. Gruell
James K. Brown
Charles L. Bushey**

PREFACE

This report incorporates new data, existing research, and experience from fire specialists, foresters, silviculturists, range managers, and wildlife biologists who deal with prescribed fire. The situations suitable for treatment of prescribed fire were identified during the planning and implementation stages of a cooperative prescribed fire demonstration study between the Jefferson Ranger District, Deerlodge National Forest and the Intermountain Fire Sciences Laboratory. The interest and enthusiasm of personnel on the Deerlodge National Forest were instrumental in the development of this guide.

The authors acknowledge technical advice from several individuals having in-depth experience in prescribed burning. Particular thanks is due Sonny Stieger, zone fuel specialist, Helena National Forest (retired); Herald Wetzsteon, forest technician, Wisdom Ranger District, Beaverhead National Forest; Dan Bailey, supervisory forestry technician, Missoula Ranger District, Lolo National Forest; Larry Keown, fire management officer, Gallatin National Forest; and John "Oz" Osborn, fire management officer, Jefferson Ranger District, Deerlodge National Forest. The following also provided constructive suggestions: Wendell Hann, Northern Region, USDA Forest Service; Peter Stickney, Intermountain Research Station; Steven Bunting, University of Idaho; John Joy, Deerlodge National Forest; Bruce Kilgore and Steve Arno, Intermountain Fire Sciences Laboratory; and Edward Mathews, Montana Division of Forestry.

RESEARCH SUMMARY

This publication is a guideline on use of prescribed fire to enhance productivity of bunchgrass ranges that have been invaded by sagebrush and conifers. Six vegetative "situations" representative of treatment opportunities commonly encountered in the Douglas-fir/grassland ecotone include seedling, sapling, and pole invasions of Douglas-fir in grasslands, a sapling/pole stage in curlleaf mountain-mahogany, a pole stage in aspen, and a sapling/pole stage in pinegrass having commercial timber potential.

Photographs and descriptions of the situations cover vegetative characteristics, vegetative trend, role of fire, response potential of plants following fire, and fire prescription considerations.

Fire prescription considerations describe the determination of resource and fire objectives, the kind of fire needed to meet the fire objectives, fuel characteristics, and possibilities for fuel modification. Photographic examples of different grass quantities and flammability aid in determining whether fire will spread.

Suggestions for planning the prescribed burns cover choosing locations and developing appropriate prescriptions. An aid in developing prescriptions includes a range of prescription factors that allow fire to carry in grasslands invaded by conifers.

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INTRODUCTION

Several million acres of seral grasslands in Montana under National Forest, National Resource (Bureau of Land Management), State, and private ownerships have been invaded by Douglas-fir or other conifers such as ponderosa pine, limber pine, lodgepole pine, or Rocky Mountain juniper. (See appendix I for scientific names of vegetation.) Before settlement, fire maintained these grasslands by impeding the invasion of conifers. The absence of fire has resulted in a marked reduction in the availability and palatability of forage, thus reducing the capability of these lands to support big game and livestock (Gruell 1983). In these situations, competition for forage between big game and livestock often becomes a significant management problem.

These guidelines focus on Douglas-fir invasion of seral grasslands on Douglas-fir bunchgrass habitat types (potential climax—Pfister and others 1977) in west-central and southwestern Montana. Focus is on Douglas-fir invasion of bunchgrass (habitat types) because of its widespread occurrence and great abundance. These habitat types have low potential for producing commercial timber, according to Pfister and others (1977). Mean yield capability is less than 30 ft^3/acre/yr. Generally, these trees are limby and of poor growth form. They are highly susceptible to damage from the western spruce budworm (*Choristoneura occidentalis*). Because of the low potential for growth of commercial timber, bunchgrass habitat types are particularly suited for management emphasis on wildlife and range values.

Interpretations of fire history and long-term succession by Arno and Gruell (1983), Gruell (1983), and Arno and Gruell (in press) demonstrate that presettlement wildfires restricted the growth of woody plants and promoted growth of bunchgrasses. Changes in environmental influences following settlement resulted in a shift toward dominance by woody plants. This shift seems to have occurred as suggested by Sindelar (1971). Livestock grazing reduced bunchgrasses and promoted soil disturbance that was favorable for establishment of sagebrush on seral grasslands. The sagebrush provided favorable microsites for regeneration of Douglas-fir seedlings. These trees became established because fire had been removed as an effective agent. Consumption of fine fuels by livestock, elimination of Indian fires, and fire suppression apparently acted independently to bring this about. Adjacent forested sites show marked increases in tree cover because of the absence of fire.

Management of forested wildlife habitat, and rangelands, largely involves maintaining desirable successional stages of vegetation. An appropriate mix of vegetation stages is usually necessary for producing a diversity of wildlife species and for maintaining high carrying capacities over long periods. Evidence of vegetation trend in Montana suggests that optimum habitat conditions for many wildlife species including mule deer (*Odocoileus hemionus*) and ruffed grouse (*Bonasa umbellus*) seem to have occurred during earlier successional stages when there was a good balance between forage and cover. Aspen and crown-sprouting shrubs had reached peak production, having responded favorably to pre-1900 fire disturbance followed by an extended fire-free period. Shrubs intolerant to fire damage including antelope bitterbrush, curlleaf cercocarpus (curlleaf mountain-mahogany), and mountain big sagebrush also reached peaks in production. As succession advanced in the absence of fire, forest openings were converted into tree cover, forests thickened, shrubs deteriorated, and bunchgrasses were reduced or eliminated. This vegetal transformation has resulted in heavy competition between wildlife and livestock for a diminishing supply of forage.

Prescribed burning has not been widely used to eliminate Douglas-fir that has invaded bunchgrass ranges. Consequently, little information is available to describe burning opportunities or assist in development of fire prescriptions. This guide identifies situations in Douglas-fir/bunchgrass habitat types where habitat capability for wildlife and forage for livestock can be improved with prescribed fire. The more moist Douglas-fir/pinegrass habitat types, frequently supporting harvestable timber, have also been included because of their shrub potential, widespread occurrence, and close association with Douglas-fir/bunchgrass habitat types. Other habitat types such as Douglas-fir/snowberry have good potential to produce shrubs during

early to mid-successional stages but are not illustrated in detail here. Where these mesic habitat types are associated with the more xeric Douglas-fir/bunchgrass habitat types, the forage resource can be enhanced by coordinating timber harvests with prescribed burning.

These guidelines are also applicable to other conifers capable of converting grassland sites. Contents should help bridge the gap between broad resource plans (such as National Forest plans and action plans) by identifying burning opportunities and approaches in application of prescribed fire.

This guide was developed around six "situations" that illustrate stages in Douglas-fir succession and associated fuels where application of prescribed fire would result in enhancement of the wildlife and range resources. The six situations described are representative of Douglas-fir succession in fire ecology groups four and five (Fischer and Clayton 1983). The situations include (1) seedling, (2) sapling, and (3) pole stages in Douglas-fir/bunchgrass habitat types; (4) a sapling/ pole stage in curlleaf mountain-mahogany on a Douglas-fir/Idaho fescue habitat type; (5) a pole stage in aspen in a Douglas-fir/rough fescue habitat type; and (6) a sapling/pole stage in a Douglas-fir/pinegrass habitat type. Situations described occur from low to middle elevations from 4,000 to 7,000 feet. The extent of each situation depends on continuity of habitat type, time since fire, and past management.

PLANNING THE PRESCRIBED BURN

Planning for a prescribed burn is a twofold process: choosing good locations and developing a prescription.

Choosing Locations

Choosing good locations for applying prescribed fire is based upon an evaluation of benefits and costs. Selected burn units should have good potential for forage response, be located where big game and livestock will use them, and be treatable with reasonable costs. The situations described here can help in identifying sites with good forage response potential. Some other considerations are briefly discussed.

The objective of using prescribed fire in most instances is to increase the carrying capacity, thus reducing the level of competition between big game and livestock. Needs for security cover should also be assessed. Most areas that will be considered for prescribed burning are winter or spring-fall range. Generally, the retention of security cover for big game in this zone is not as important as on summer range where animals remain during most of the hunting season. Nonetheless, evaluation of security cover needs of big game should be made on a case-by-case basis.

On most livestock allotments, it is advisable to rest treated units prior to burning and during the first growing season. This can be followed by light to moderate late-season grazing. An important consideration in maintaining good postfire response is to treat a large enough area that use by livestock and wildlife will not be excessive. Where forage use is heavy, this may require treating a thousand acres or more.

We suggest that initial planning be focused on identification of treatment alternatives throughout a drainage basin. Opportunities to integrate timber harvests into the treatment alternatives can facilitate attainment of objectives, especially on sites having good potential for aspen and shrubs. For example, patch cuts followed by broadcast burning can be designed to reduce fuels and stimulate growth of forage plants. Cutting units may also serve as holding lines for subsequent prescribed burns in adjacent uncut areas.

A primary consideration in keeping costs down is size of burns. Costs per acre treated increase rapidly for units less than about 80 acres. Time of year also affects costs. For example, burning during late summer and early fall requires more effort to prepare and hold lines, which increases costs substantially.

Large burns make it easier to take advantage of natural fuel breaks and changes in vegetation to control fire. Use of natural fuel breaks will keep costs down, while eliminating damage that may occur from fire line construction. The size of the burn depends on complexity of the project. Factors to consider include the season of livestock use, travel restrictions, private property, mining activity, recreationists, and so forth. The manager should try to burn as large an area as possible. This can be accomplished by burning single units or several smaller units close together.

The situations described here often intermingle on the landscape (fig. 1). Therefore, more than one situation may be included in a single burn unit. After situations are identified, the most logical treatment sequence can be determined.

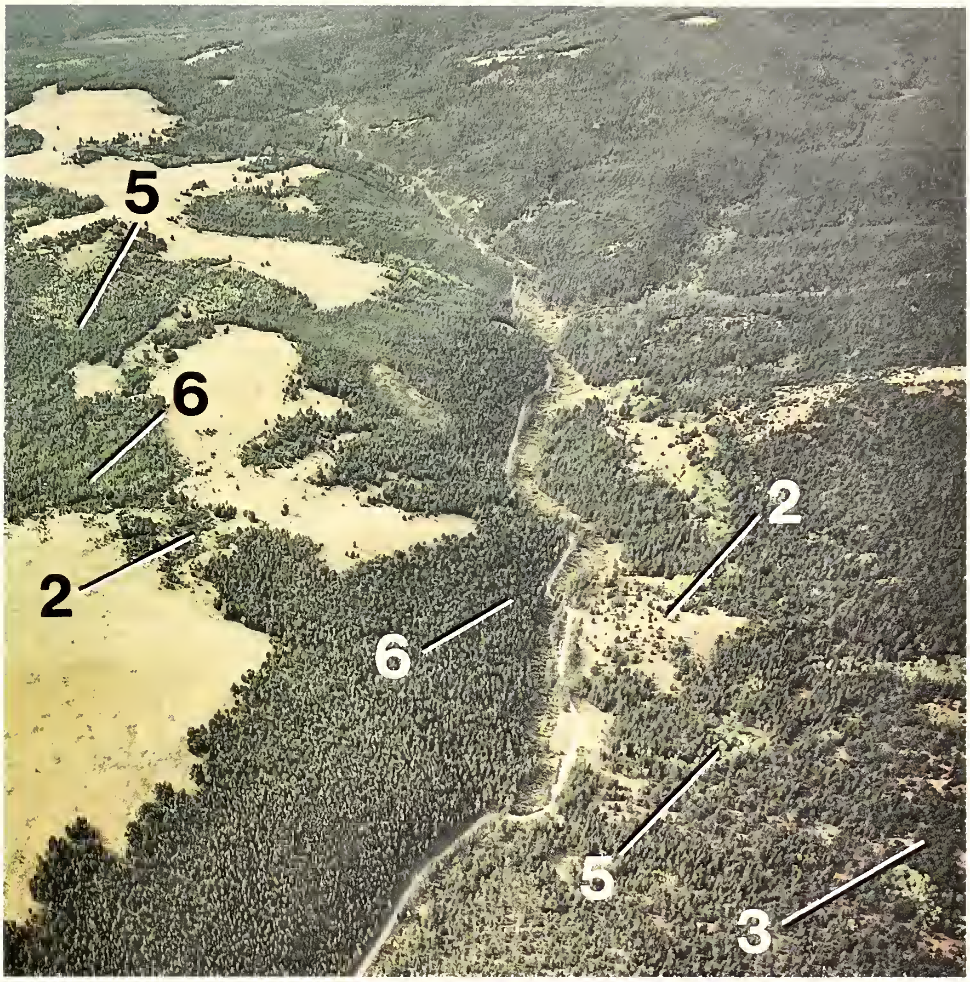

Figure 1.—Examples of situations on Galena Gulch study area. Numbers follow sequence in text.

Developing the Prescription

Although this publication provides some specific fire prescription suggestions, it is not intended to be a detailed guide for writing prescriptions. Because prescribed fire opportunities are often unique, they should be evaluated individually. To determine safe, effective fire prescriptions, the first step is to specify objectives for the fire and define constraints on using it. Next consult technical aids for evaluating fuels, weather, fire behavior, and fire effects. Then integrate relevant technical knowledge with experience to write the prescription. This process, along with considerations for choosing technical aids appropriate to defining prescription windows, are discussed by Brown (in 1985). References useful for planning prescribed fire, in addition to those cited earlier, are listed in the reference section.

A range in prescription factors used in prescribed burning grass invaded by sagebrush is shown in table 1. These values were determined by interviewing people experienced in prescribed burning of sagebrush. The values in table 1 do not constitute a prescription for any individual site but indicate the latitude within which prescriptions can be developed. Local fuel conditions and terrain will dictate whether individual prescriptions should promote or retard flammability. For example, on a steep slope with reasonably continuous fuels, windspeeds of 3 to 7 mi/h and relative humidities of 25 to 40 percent may constitute a desirable prescription for those factors. However, on an area with little slope and sparse fuels, windspeeds of 6 to 12 mi/h and relative humidities of 15 to 30 percent may constitute a desirable prescription.

To help find the answer on whether fire will spread in grass fuels, appendix II includes photographic examples of different grass quantities and associated flammability. Experience with prescribed fire on grazed range indicates that fine fuel loadings will not support fire spread unless accompanied by at least 15 to 20 percent sagebrush cover. The lightly grazed example may allow fire to burn in some localities, but the broken fuel continuity could interrupt fire spread unless sagebrush cover is at least 10 percent. The ungrazed example will support fire spread. Fire intensity is increased with the addition of sagebrush.

Table 1.—Range of prescription factors that allow fire to carry in grasslands invaded by big sagebrush and Douglas-fir. The range in prescription factors for individual burns may be smaller to satisfy local fuel and terrain conditions

Situation	Average windspeed	Cloud cover	Temperature	Relative humidity	Fuel moisture 1-hour timelag	Fuel moisture 10-hour timelag	Time of year
	Mi/h	*Percent*	°F	*Percent*			
1. Sagebrush, grass, Douglas-fir seedlings	3 to 12	0 to 10	50 to 80	15 to 40	6 to 12	8 to 15	spring, fall
2. Sagebrush, grass, Douglas-fir saplings	3 to 12	0 to 10	55 to 80	15 to 40	6 to 12	8 to 15	spring, fall
3. Mountain-mahogany, sagebrush, grass, Douglas-fir seedlings and saplings	5 to 12	0 to 10	55 to 80	15 to 40	6 to 12	8 to 15	spring, fall
4. Douglas-fir pole stage in sagebrush and grass	3 to 8	0 to 20	50 to 75	25 to 60	6 to 15	8 to 18	fall
5. Douglas-fir pole stage in aspen	4 to 10	0 to 10	55 to 80	20 to 40	6 to 12	8 to 15	fall (preferred) spring
6. Douglas-fir saplings and poles, pinegrass and shrub understory	3 to 8	0 to 20	50 to 80	25 to 60	6 to 15	8 to 18	fall

Two aspects of the prescription—season of burning and the combined influence of fine fuel moisture and windspeed on flammability—merit additional comment. A tradeoff between windspeed and fine fuel moisture or relative humidity is sometimes possible in achieving sustained fire spread. For example, increased windspeed can overcome the damping effect of slightly high relative humidity. Conversely, low relative humidities can sometimes overcome lack of wind. Experience is needed to recognize when the tradeoffs are effective in maintaining fire spread. Caution is advised in basing prescriptions on the flammable and nonflammable limits of relative humidity and windspeed shown in table 1. When windspeeds are high and relative humidities low, for example, control of fire may be difficult. Conversely, when windspeeds are low and relative humidities high, fire may not spread. The season when prescribed fires are scheduled affects the attainment of objectives and cost effectiveness.

Spring Fires.—These fires are conducted as soon as dead fine fuel moistures are low enough to support fire spread but before green up of herbaceous vegetation. New green growth should be less than 2 inches in height to favor sustained fire spread with minimal damage. Fine fuel moisture contents as low as 5 percent may be acceptable in the spring but present control difficulties during other seasons, depending on other burning conditions. In large burns where differences in elevation and aspect affect flammability, stage burning may be needed to meet objectives. This requires on-site monitoring of fuel moisture to know when different sections of the burn are in prescription. Spring burns tend to produce a mosaic of burned and unburned areas, which is usually desirable for meeting wildlife habitat objectives in sagebrush. Small burns as well as large ones that create a mosaic can be cost effective. But obtaining large burned-over areas may be difficult and costly. Some advantages and disadvantages of spring burning are:

Advantages
- Small Douglas-fir are easily scorched and killed
- Soil moisture content is high and damage to sensitive bunchgrasses such as Idaho fescue is minimal unless fires are set too late in the spring
- Burns are less complex and less expensive than at other seasons
- Smoke dispersion is good

Disadvantages
- The prescription window or time in prescription is short and even absent in some years
- Access can be a problem
- Poor site preparation results where forest floor duff (02 horizon) has accumulated
- Moist fuels beneath conifers prevent spread of fire

Fall Fires.—Fall burning period is usually considered the time after late summer rains have broken the normal fire season. Many plants have ceased growth and are dormant. A wide latitude in fuel moisture content, fuel consumption, soil moisture content, and fire effects is possible. This adds to the complexity of fall burning. Objectives of prescribed fires must be evaluated carefully to determine proper scheduling during the fall. Late summer burning may be appropriate to meet objectives for substantial exposure of mineral soil. Large areas of sagebrush can often be inexpensively burned. Some advantages and disadvantages of fall burning are:

Advantages
- Good site preparation can be obtained
- The time in prescription is longer than at other seasons
- There is better access than in the spring
- Fire spreads more readily on wetter sites
- Ceanothus regenerates well where dormant seeds are present

Disadvantages

- Burns may be more complex and expensive than at other seasons
- Wind erosion is possible in areas susceptible to strong sustained wind
- Smoke dispersion may constrain opportunities

SITUATIONS

Each situation is illustrated by a photograph accompanied by a description of vegetation and fuels found in the scene. The quantitative information was obtained by sampling within the scene areas. Because vegetation and fuels vary from site to site within a situation, the photographs must be considered as examples only.

Vegetation and fuels were measured as described in appendix III. Fine fuel and litter measurements closely follow procedures developed by Brown and others (1982). Herb and shrub composition (presence/absence) was determined by reconnaissance within the field of view.

Following each scene are discussions of vegetal characteristics and trend, response potential, and fire prescription considerations.

SITUATION 1: Douglas-fir Seedling Stage in a Douglas-fir/Idaho Fescue h.t.

SITE CHARACTERISTICS

Density

Trees[1] (No./acre)	Trees[1] Basal area (Ft²/acre)	Seedling and sapling[2] (No./acre)
10	1	35,000

Cover (percent)

Trees	Shrubs
8	27

Fuel loading (lb/acre)

Grass and litter	2,980
Live shrub	1,940

Herb and shrub composition

Rough fescue, Idaho fescue, bluebunch wheatgrass, western yarrow, western puccoon, heartleaf arnica, fernleaf fleabane, fringed sagebrush, rubber rabbitbrush, mountain big sagebrush

[1]Trees over 10 feet high.
[2]Trees less than 10 feet high.

VEGETATION CHARACTERISTICS

Situation 1 is an example of Douglas-fir seedlings invading a seral sagebrush/bunchgrass community on a Douglas-fir/Idaho fescue habitat type. This situation is generally restricted to openings of less than 2 acres. Adjacent conifer stands vary in age and structure. In our example, the Douglas-firs in the background are sapling and pole sizes while conifer seedlings are abundant (35,000 per acre). The high number of seedlings reflects dense patches less than 2 feet high that are screened by sagebrush. Sagebrush has a canopy cover of about 27 percent. Bunchgrasses include Idaho fescue, rough fescue, and bluebunch wheatgrass, while forbs form a minor part of the plant cover on this semiarid site.

VEGETATION TREND

Examination of fire scars in the vicinity suggests that the absence of fire for about 100 years allowed Douglas-fir to invade this park, which was formerly dominated by grass. Douglas-fir was preceded by establishment of sagebrush that provided shaded microsites conducive to regeneration of Douglas-fir seedlings. If fire is excluded, Douglas-fir seedlings will reach sapling size within the next 20 years.

Antelope bitterbrush may be an important component of the vegetation, but it is often senescent, showing little evidence of seedling regeneration. Continued protection from disturbance, particularly where conifer competition is intense, will result in extensive long-term decline and eventual loss of bitterbrush from the community (Bunting and others 1985).

RESPONSE POTENTIAL

Use of prescribed fire reduces or eliminates Douglas-fir seedlings and sagebrush and improves growing conditions for a variety of forage plants by increasing available soil moisture, nutrients, and sunlight. The response potential of grasses and forbs will vary depending on preburn composition and density. Herbage production may be less than preburn levels the first growing season, but can be expected to increase threefold or more by the fifth growing season (fig. 2). Curves on figure 2 are generalized to show average responses. The level of production will vary by site depending on several variables, particularly soil moisture during the growing season. A decline in forage production to preburn levels after 20 years is based on the assumption that sagebrush competition will be intense.

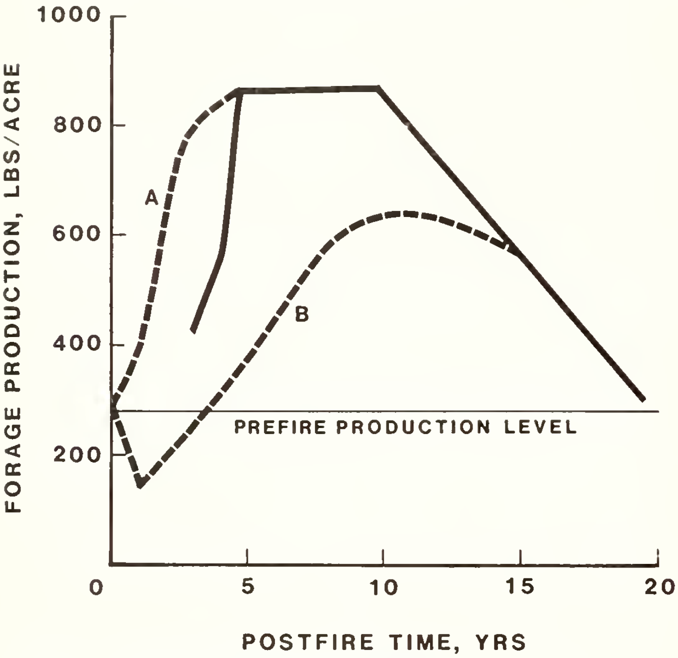

Figure 2.—Forage production after disturbance by fire. Solid line is for grasslands largely based on data from Idaho and Oregon (Peterson and Flowers 1985). Dashed curves show rapid increase in production recorded in central Montana (A) and slower, less productive situations where conifer competition was severe (B).

Wheatgrasses.—Wheatgrasses recover quickly because reproductive buds are located below the soil surface where they are protected from heat. Bluebunch wheatgrass usually returns to preburn conditions in 1 to 3 years (Wright and others 1979). Rhizomatous species in particular have the capability of recovering quickly. Nimir and Payne (1978) reported a 42 percent increase in the basal area of slender wheatgrass at the end of the first growing season after a light spring burn in southwest Montana. Production may remain above preburn levels for a decade or longer. A twofold increase in bluebunch and thickspike wheatgrasses was measured in southeastern Idaho 12 years after an intense late summer prescribed fire (Blaisdell 1953).

Needlegrasses.—Production of most needlegrasses is initially reduced by fire. The degree of reduction seems to depend upon species and season of burning (Wright and others 1979). Needle-and-thread grass showed high mortality to June and July burns, but no mortality was recorded in response to August treatments (Wright and others 1979). First-year production of western needlegrass was reduced by an August wildfire in northeastern California, but by the third year its basal area had almost doubled in comparison to an adjacent unburned area (Countryman and Cornelius 1957). An apparent extreme in needlegrass response was measured in southwestern Montana where Richardson needlegrass in a rough fescue habitat type increased from 4 lb/acre to 306 lb/acre 2 years after a spring prescribed fire. This site had a heavy preburn canopy of mountain big sagebrush (Bushey 1984). In west-central Montana Hann (1984) found a marked increase in production of western needlegrass over the preburn level on a Douglas-fir/rough fescue habitat type.

Idaho Fescue.—Fescues usually respond more slowly to fire than do other grasses. Idaho fescue, one of the most widespread grass species in Montana, is particularly sensitive to fire. Susceptibility to damage is apparently due to the compact root crown with the budding zone confined to a small area at or above the soil surface (Conrad and Poulton 1966).

Idaho fescue took 30 years to approach preburn levels in southeastern Idaho (Harniss and Murray 1973). Slow recovery was apparently influenced by marginal site conditions (Wright and others 1979) and a high-intensity late summer fire fueled by dense sagebrush.

Observations in Montana suggest that the susceptibility of Idaho fescue to loss from fire increases proportionately to the amount of dead fescue. Bunchgrass clumps with accumulated biomass may smolder for long periods. This permits lethal temperatures to develop around meristematic tissue. Idaho fescue in association with sagebrush is also influenced by fire severity. Sites with heavy sagebrush cover can generate severe fires, thus damaging or killing Idaho fescue. In northeastern Oregon measurements 11 months following a summer wildfire showed 27 percent mortality of Idaho fescue (Conrad and Poulton 1966), whereas fall burning in eastern Oregon when plants were dormant resulted in no mortality (Wright and others 1979). In western Montana, Antos and others (1983) report recovery of Idaho fescue to preburn levels 3 years after a summer wildfire.

The effects of fire on Idaho fescue vary greatly depending on timing of the burn, plant condition, and fuel loading. Damage to Idaho fescue can be minimized by burning in the spring or fall when plants are dormant.

Losses of Idaho fescue to prescribed fire should be kept in management perspective. Few areas exist in western Montana where the productivity potential of Idaho fescue justifies management for this species (Hann 1985). Generally, management should be for bluebunch wheatgrass, mountain brome, western needlegrass, and other productive and palatable species.

Where such grasses predominate, high mortality of Idaho fescue from an intense fire need not be a critical management concern.

Rough Fescue.—Many seral grasslands invaded by Douglas-fir contain rough fescue. This species generally responds favorably to prescribed fire in the long run. Productivities of 800 to 1,600 lb/acre have been reported on unburned sagebrush/rough fescue habitat types (Mueggler and Stewart 1980). Rough fescue is considered fire sensitive because the budding zone is at or above the soil surface. According to Antos and others (1983), burning of the dense stubble of old culms materially contributes to plant losses. These investigators report that at the end of the first growing season following a summer wildfire in western Montana, rough fescue cover was 35 percent of that in unburned control stands. By the third year, rough fescue production had reached 65 percent of that in unburned stands. On spring prescribed burns in west-central Montana, no loss of rough fescue plants was reported 1 year following the fire (Bushey 1984; Hann 1984).

Application of prescribed fire in seral grasslands invaded by Douglas-fir may entail acceptance of short-term reductions in perennial grasses in order to achieve long-term gains. Most grasses show a twofold or more increase in production by the third year after treatment with prescribed fire. Initial reductions in fescues are usually compensated by the rapid response of other grasses.

Shrubs.—Use of prescribed fire on situation 1 sites should result in marked reduction in nonsprouting sagebrush. Postfire establishment of sagebrush seedlings may occur the first year or be delayed several decades depending on sagebrush species or subspecies, seed availability, soil disturbance, and competition from herbaceous plants. Sprouting sagebrush such as three-tip sagebrush and silver sagebrush may be present on adjacent moist sites.

Burning of sagebrush and Douglas-fir will kill bitterbrush on sites where the fire is severe. However, because bitterbrush is disturbance dependent, use of prescribed fire is ecologically sound when viewed on a long-term basis (Bunting and others 1985). A light to moderate severity prescription usually produces a mosaic of burned and unburned areas. Burning results in crown sprouting of surviving bitterbrush plants and exposure of mineral soil necessary for seedling establishment. Bitterbrush plants in unburned areas serve as seed sources for new plants, while surviving plants that crown sprout ultimately produce seed for establishment of new stands of bitterbrush.

PRESCRIPTION CONSIDERATIONS

Resource Objective.—Increase productivity of herbaceous vegetation, particularly grasses (fig. 2), and improve palatability.

Fire Objectives.—Kill 60 to 80 percent of the sagebrush and 60 to 80 percent or more of the Douglas-fir. Lack of continuous fuels usually results in patchy burns, so complete removal of sagebrush and Douglas-fir seedlings is not a realistic goal. Retention of some sagebrush may be desirable especially for wildlife needs such as winter range for mule deer.

Kind of Fire.—A heading fire with 2-foot or greater flame lengths is needed to kill the sagebrush and Douglas-fir seedlings. A fire with smaller flames probably would not sustain itself. Strip head fires with large distances between strips usually work well. However, narrow strips with fast ignition may be more effective where fuels are marginally sparse. A wide latitude exists for individual prescriptions (table 1). To satisfy local fuel and terrain conditions, the range in prescription factors determined as appropriate for individual burns will normally be smaller than in table 1. For large burns the more flammable end of the prescription spectrum should be sought. For example, seek windspeeds of 8 to 12 or 14 mi/h at 20 feet above vegetation, relative humidity near 20 percent, and temperatures above 65 degrees. Windspeeds can be too high, causing fires to skip through vegetation without killing it. Windspeeds greater than 15 mi/h can cause fires to burn in a finger pattern and even go out. The resulting disruption in fuel continuity makes it difficult to complete the burn at a later time.

Fall burning should be done after grasses have become dormant. Although it has been commonly believed that soil should be moist during fall burning, recent evidence indicates that moist soil offers no advantage to survival of Idaho fescue (Britton and others 1983). Caution seems advised, however, in applying this finding to bunchgrasses having large basal clumps containing accumulated dead material. When dry, these clumps are susceptible to crown kill from smoldering fire. Midsummer burning is not recommended because some herbaceous plants such as Idaho fescue are very susceptible to mortality. Spring burning should be done while desirable, sensitive perennial species are still dormant and before green-up reduces flammability. This applies to all situations where desirable fire-sensitive perennial species occur.

Fuels.—Successful spread of fire requires adequate grass fuel (see appendix II). Exclusion of livestock for one season is frequently necessary to develop adequate grass fuel. Where coverage of sagebrush is less than about 15 percent, a grass loading of about 600 lb/acre is needed to support fire (Britton and Ralphs 1979). For sagebrush coverage greater than about 20 percent, 300 lb/acre of grass may be adequate. Ample grass fuel is particularly needed at lower windspeeds to sustain fire spread, ignite sagebrush, and scorch seedlings. These marginal fuel loadings may be reduced on slopes exceeding about 40 percent. Steep slopes can increase windspeed (Rothermel 1983). Thus, to some extent steep slopes can overcome lack of wind to attain sustained fire spread.

SITUATION 2: Douglas-fir Sapling Stage in a Douglas-fir/Idaho Fescue h.t.

SITE CHARACTERISTICS

Density		
Trees[1]		Seedling and sapling[2]
(No./acre)	Basal area *(Ft²/acre)*	*(No./acre)*
60	13	8,700

Cover *(percent)*	
Trees	Shrubs
8	12

Fuel loading *(lb/acre)*	
Grass and litter	5,060
Live shrub	840

Herb and shrub composition

Bluebunch wheatgrass, Idaho fescue, needle-and-thread, junegrass, Richardson needlegrass, carex, western yarrow, aster, fringed sagebrush, Missouri goldenrod, bitterbrush, mountain big sagebrush, rubber rabbitbrush

[1]Trees over 10 feet high.
[2]Trees less than 10 feet high.

VEGETATION CHARACTERISTICS

Situation 2 illustrates the sapling stage of Douglas-fir invasion in sagebrush/bunchgrass on a Douglas-fir/Idaho fescue habitat type. This stage is typified by trees 30 to 50 years old. Pole-size Douglas-fir can be seen in the background of the accompanying photo. Note the Douglas-fir seedlings in foreground and midground. The Douglas-fir saplings in our example number 8,700 per acre. On this site, shrub cover is 15 percent and is composed of sagebrush, bitterbrush, and rubber rabbitbrush. In general, both sagebrush and bitterbrush are in a declining condition because of competition from trees, insect defoliation, and other biotic factors. The herbaceous vegetation includes five bunchgrasses, a sedge, and several forbs. The potential for herbaceous plants generally is good on sites occupied by saplings because soils are deep and have a relatively high capacity to retain moisture.

VEGETATION TREND

Aging of Douglas-fir on Douglas-fir/bunchgrass habitat types indicates that before settlement these lands were occupied by bunchgrass (Arno and Gruell in press). Small clumps of trees were often found on restricted rocky microsites or thin soils where fuels were sparse. Grasslands were perpetuated by fires burning at intervals of about 5 to 40 years. In the absence of fire, shrubs increased greatly. Recently, however, productivity of shrubs has declined due to senescence of individual plants and conifer competition. Herbaceous plants have also declined. In the absence of fire or insect attack, these stands will reach the pole or sawlog stage in another 40 to 50 years. At this point, little herbaceous forage or live shrubs will remain beneath the tree canopies.

RESPONSE POTENTIAL

The potential for herbaceous plant response on situation 2 sites is higher than on situation 1 sites because soils are deeper and thus have a greater productivity potential. This favorable condition has coincidentally promoted invasion of Douglas-fir. Generally, sufficient numbers of forage plants are present to respond to fire treatment, but recovery potential may be low in Douglas-fir thickets where shading has reduced the herbaceous layer. These sites may recover slowly, particularly if the fire treatment is severe. However, if the fire treatment is light and desired tree mortality is not achieved, a followup treatment within 10 years could produce satisfactory results.

Although prescribed fire may result in reduced production of perennial grasses temporarily, increased productivity will occur in a few years and can be expected to continue for about 20 years, providing enough area is burned to absorb grazing impacts. Use of prescribed fire on situation 2 sites supporting bitterbrush is especially important. At the sapling stage, many bitterbrush plants have been lost to Douglas-fir competition, but there are sufficient numbers of living plants to assure regeneration of the stand. A no-treatment alternative would eventually result in a wildfire. Recovery of bitterbrush following wildfire would be extremely slow.

PRESCRIPTION CONSIDERATIONS

Resource Objective.—Increase productivity of herbaceous vegetation—same as situation 1.

Fire Objective.—Kill 60 to 80 percent of the sagebrush and 60 to 80 percent or more of Douglas-fir—same as situation 1.

Kind of Fire.—A heading fire with 3-foot and greater flame lengths is needed to kill the sagebrush and small saplings. Larger flames will be needed to kill saplings 4 to 5 inches diameter at breast height (d.b.h.). The primary difference between situations 1 and 2 is the

requirement for greater fire intensity to kill the larger Douglas-fir. Dense sapling thickets with sparse understories are difficult to burn. Strip head fires are usually the most appropriate ignition method. Aerial ignition of strip head fires offers a method of generating a lot of heat quickly and creating indrafts that could help in burning out thickets. The latitude for development of prescriptions is nearly the same as for situation 1, table 1, except that temperatures and humidities prescribed for individual units should be selected to support greater flame development.

Fuels.—The need for grass fuels discussed in situation 1 applies here as well. Treatment of the conifer fuels should usually be unnecessary. However, cutting of some saplings in large thickets will add to the fuel load and increase drying of fuels. This will enhance burnout of thickets and should be considered where it will help sustain fire spread and maintain adequate fire intensities.

SITUATION 3: Douglas-fir Pole Stage in a Douglas-fir/Rough Fescue h.t.

SITE CHARACTERISTICS

Density

Trees[1] (No./acre)	Trees[1] Basal area (Ft²/acre)	Seedling and sapling[2] (No./acre)
160	135	—

Cover (percent)

Trees	Shrubs
49	2

Fuel loading (lb/acre)

Grass and litter	3,450
Live shrub	120

Herb and shrub composition

Rough fescue, Idaho fescue, junegrass, carex, bluebunch wheatgrass, Richardson needlegrass, sulfur eriogonum, common dandelion, prairiesmoke, strawberry, western yarrow, squaw currant, mountain big sagebrush, rose, chokecherry

[1]Trees over 10 feet high.
[2]Trees less than 10 feet high.

VEGETATION CHARACTERISTICS

Situation 3 illustrates a pole or small sawlog stage of Douglas-fir invasion that began 70 to 100 years ago. This stage of Douglas-fir succession is widespread on former grasslands but varies in stocking density. Stands may be even-aged, such as shown in the illustration, or be intermixed with varying densities of saplings and seedlings. Shrub cover is usually minimal, with only a few remnant crown-sprouting species such as squaw currant, rose, or snowberry present. The low-density herbaceous cover is mostly perennial bunchgrasses with a few forbs.

VEGETATION TREND

In the absence of fire after the mid-1800's, sagebrush invaded grasslands and eventually these shrubs provided shaded microsites for establishment of Douglas-fir seedlings. Sagebrush remnants at the base of trees attest to a sagebrush/grass community in the past (fig. 3). Establishment of trees on former grasslands such as illustrated in our example has resulted in significant reduction of the bunchgrass cover. Shading and accumulation of litter beneath tree crowns (fig. 4) have suppressed the growth of grasses and prevented establishment of grass seedlings. In some stands, near total loss of the grass cover has occurred.

Figure 3.—Sagebrush remnants at base of Douglas-fir provided shaded microsite for establishment of Douglas-fir seedlings.

RESPONSE POTENTIAL

Pole stands generally occupy deep soils that have good potential for producing herbaceous plants. However, herb response to disturbance will vary depending on recovery potential, which is related to tree density and herb presence. The response of herbs will depend on the amount of tree mortality caused by treatment. Felling (cutting) and broadcast burning is likely to result in a

Figure 4.—Douglas-fir needle litter accumulation limits growth of grassland understory plants.

better forage response than burning alone. Only a severe fire will kill pole-sized Douglas-fir, and considerable mortality is necessary to induce a major forage response. Delayed response of herbs may result where fuels are concentrated. From observations of burns in heavy conifer, we speculate that production will be delayed and will not reach production levels comparable to sagebrush sites (fig. 2).

PRESCRIPTION CONSIDERATIONS

Resource Objective.—Increase productivity of herbaceous vegetation. Retain tree cover for big game animals and birds.

Fire Objectives.—Remove at least 70 percent of litter layer and expose 30 to 60 percent mineral soil to favor establishment of grass seedlings. Retain 20 to 30 live pole-sized Douglas-fir per acre in an irregular spacing for wildlife and esthetic values (this objective may vary according to needs on individual sites).

Kind of Fire.—A strip head fire with flame lengths regulated to save 20 to 30 trees per acre is desirable. Flame lengths should be kept less than 2 feet around the trees to be saved. Backing fires are acceptable where fuel continuity is adequate to sustain fire spread. Lower duff moisture content should average less than 100 percent and moisture content of the entire duff layer should average less than 75 percent to achieve adequate mineral soil exposure (Brown and others 1985). If duff moisture content at time of burning is less than 100 percent, the desired mineral soil objective can be met with a low-intensity fire. Flame lengths of 1 to 2 feet are adequate. A late summer or early fall burn normally will be required to meet the duff moisture prescription. Once duff becomes wet in early fall from rainfall of about 1 inch or more, it is unlikely that the duff will dry sufficiently to meet the prescription.

Fine fuel moistures can be higher than in the other situations if slash is present (table 1). If slash is not present, fine fuel moisture contents should be at the low end of the range in table 1.

Fuels.—Surface fuels in this situation are commonly sparse. Fires typically leave many trees alive because the sparse fuels generate insufficient heat to cause mortality. Treatment objectives can be accomplished more effectively by harvesting and using trees for fuelwood or other products. Slash from harvesting increases fuel loading and improves fuel continuity. Slash should be scattered away from leave trees. Opportunities for harvesting should be sought to provide both wood products and improved wildlife habitat.

SITUATION 4: Douglas-fir Sapling/Pole Stage in Curlleaf Mountain-mahogany on a Douglas-fir/Idaho Fescue h.t.

SITE CHARACTERISTICS

Density

Trees[1]		Seedling and sapling[2]
(No./acre)	**Basal area** *(Ft²/acre)*	*(No./acre)*
40	1	1,500

Cover *(percent)*

Trees	Shrubs
7	14

Fuel loading *(lb/acre)*

Grass and litter	2,370
Live shrub	190

Herb and shrub composition

Bluebunch wheatgrass, Idaho fescue, needle-and-thread, junegrass, western yarrow, prairie smoke, fringed sagebrush, Missouri goldenrod, strawberry, mountain big sagebrush, snowbrush ceanothus, curlleaf mountain-mahogany, chokecherry, green rabbitbrush, squaw currant, rose

[1]Trees over 10 feet high.
[2]Trees less than 10 feet high.

VEGETATION CHARACTERISTICS

Situation 4 illustrates a sapling/pole stage of Douglas-fir in a Douglas-fir/Idaho fescue habitat type that is growing in association with curlleaf mountain-mahogany, sagebrush, and other woody plants and herbs. Shrub cover, not including the mountain-mahogany, is 14 percent in our example. Sagebrush, or bitterbrush, may be present. Localized inclusions of crown-sprouting shrubs including chokecherry, snowbrush ceanothus, and squaw currant may also occur. Production of herbaceous plants varies considerably.

VEGETATION TREND

Historically, mountain-mahogany was restricted to rock outcrops or sites where sparse fuels afforded protection from frequent surface fires (Gruell and others 1985). Frequent fires prevented conifers and curlleaf mountain-mahogany from becoming established wherever fuel accumulated. In the absence of fire, mountain-mahogany, conifers, and various shrubs invaded. On sites such as that pictured, conifers are becoming highly competitive. As a consequence, mountain-mahogany are being displaced where they are in direct competition with conifers (fig. 5). Some mountain-mahogany are also dying from effects of insects (fig. 6). Without fire or cutting, mountain-mahagony and associated shrubs will continue to decline as Douglas-fir increases dominance of the site. Productivity of herbaceous vegetation will also decline. The continued absence of fire will increase the chances of hot wildfires that have the potential of killing mountain-mahogany over wide areas.

Figure 5.—Displacement of mountain-mahogany by Douglas-fir.

Figure 6.—Loss of mountain-mahogany to insects.

RESPONSE POTENTIAL

Where Douglas-fir are competitive, curlleaf mountain-mahogany can be regenerated by cutting or use of prescribed fire (Gruell and others 1985). Mountain-mahogany is likely to regenerate if conifer competition is substantially reduced and mineral soil is exposed. Because curlleaf mountain-mahogany is a weak sprouter, its reestablishment depends upon seed dispersal from adjacent sites or surviving plants within the burn that were not killed. Where ungulate browsing is heavy, the area treated should include hundreds or thousands of acres in order to minimize impacts on new seedlings.

PRESCRIPTION CONSIDERATIONS

Resource Objective.—Increase productivity of herbaceous vegetation and promote regeneration of curlleaf mountain-mahogany by establishment of seedlings.

Fire Objectives.—Kill 50 to 75 percent of the Douglas-fir and sagebrush to reduce competition. Remove litter and expose mineral soil to favor establishment of curlleaf mountain-mahogany seedlings.

Kind of Fire.—A mosaic of burned and unburned areas is desirable. Normally, this kind of mosaic results from fire in rocky, broken terrain occupied by mountain-mahogany because fuels are discontinuous. In the areas where fuels are continuous, a heading fire with 3-foot and greater flame lengths is needed to kill the Douglas-fir and sagebrush. Where fuels are sparse and discontinuous, sustained fire spread is frequently difficult to achieve. Mountain-mahogany often exists in these areas and survives fire to supply seeds for establishment of new plants.

For the same fuels and terrain, higher windspeeds than needed in situations 1 and 2 may be desirable to help spread fire through sparse fuels. Otherwise, prescription conditions are the same as for situations 1 and 2 (table 1). Ignition effort should concentrate on the patches of continuous fuels to efficiently accomplish the mosaic of burned and unburned areas. Aerial ignition can be used to advantage where large burns, especially in remote areas, are planned. Spring and fall burning are both possible. However, fall burning may be necessary to achieve success where coverage of Douglas-fir and mountain-mahogany and topographic exposures cause fuels to dry slowly in the spring.

Fuels.—Control of grazing, as in situation 1, may be necessary to assure sufficient grass fuel to help carry the fire. Where possible, slash from harvesting would increase flammability and make it easier to accomplish the objectives of removing conifers.

SITUATION 5: Douglas-fir Pole Stage in Aspen in a Douglas-fir/Rough Fescue h.t.

SITE CHARACTERISTICS

Density

Trees[1]		Seedling and sapling[2]
(No./acre)	Basal area *(Ft²/acre)*	*(No./acre)*
230 (conifer)	89	38,000
210 (aspen)	38	10,000

Cover *(percent)*

Conifers	Aspen	Shrubs
45	20	1

Fuel loading *(lb/acre)*

Grass and litter	4,250
Live shrub	20
Downed dead woody 0-3 inches	9,470
TOTAL	13,740
Downed dead woody 3+ inches	5,950

Herb and shrub composition

Rough fescue, Idaho fescue, pinegrass, Richardson needlegrass, junegrass, oatgrass, common dandelion, Missouri goldenrod, strawberry, western yarrow, lupine, violet, squaw currant, kinnikinnick

[1]Trees over 10 feet high.
[2]Trees less than 10 feet high.

VEGETATION CHARACTERISTICS

Situation 5 depicts a pole stage of Douglas-fir outcompeting aspen that apparently regenerated following an extensive fire in about 1846 (Arno and Gruell in press). Stands usually support a low density of crown-sprouting shrubs because of intense shading from conifers. Our example shows few shrubs on a site having good shrub potential.

VEGETATION TREND

In the absence of fire, aspen stands in the northern and middle Rocky Mountains have reached maturity and many have deteriorated (Gruell and Loope 1974; Gruell 1980, 1983; Krebill 1972; Schier 1975). Widespread evidence of remnant aspen beneath conifers shows that sites now dominated by conifers were once occupied by aspen. Historically, frequent fires stimulated aspen suckering and kept stands in the drier Douglas-fir community types in earlier stages of succession. As our example indicates, suckers may be present in deteriorated stands, but few will develop into trees. In stands where suckers are present, their growth is often suppressed because of browsing by livestock and wild ungulates.

Continued protection of aspen from disturbance will result in accelerated losses of clones. Wildfires can rejuvenate healthy clones, but the recovery potential of deteriorating clones will be markedly reduced in the coming decades. Fewer aspen will be alive to respond to disturbance, and the vigor of parent root systems will be reduced.

RESPONSE POTENTIAL

Aspen usually regenerate vegetatively by suckers that emerge from lateral roots after the aboveground stems are killed (Schier 1975). Sucker response varies depending upon the viability of the root system and severity of disturbance. Light burns produce marginal results because few parent stems are killed by the fire. Moderate-severity fires seem to produce the best results (Horton and Hopkins 1966). These fires kill nearly all of the parent stand, thereby stimulating sucker formation. Sucker densities 1 year after burning have ranged from 3,000 to 60,000 per acre (Brown 1985a; Bartos 1981). Cutting also stimulates sucker production and can be used alone or with fire to rejuvenate the aspen type.

Aspen can reproduce by seed (McDonough 1979), although establishment of new stands from seed has seldom been documented in the Western United States. Establishment requirements include a continuously moist seedbed of mineral soil. Mineral soil can be achieved by mechanical scarification or prescribed fire.

Most aspen stands have the potential of supporting a variety of herbs and shrubs. The use of prescribed fire enhances understory production by stimulating crown sprouting and providing mineral soil for seedling establishment.

Burned sites attract big game and livestock. Small burned areas concentrate animal use and tend to result in excessive damage to aspen sprouts and other forage plants. Areas of at least several hundred acres should be burned to minimize excessive damage. Burning a number of smaller units near each other within the same year might also disperse animal impacts. These can be planned to create a mosaic of fire-treated and unburned vegetation. Single large burns are the most cost-effective approach.

PRESCRIPTION CONSIDERATIONS

Resource Objective.—Maintain vigorous aspen clones and increase productivity of herbaceous vegetation and shrubs.

Fire Objectives.—Kill 80 percent or more of standing aspen to stimulate suckering and kill 80 percent or more of the conifers to minimize conifer competition during early succession. Expose 30 to 50 percent mineral soil to encourage establishment of shrub seedlings and herbaceous plants.

Kind of Fire.—A heading fire with 2-foot and greater flame lengths is needed to kill aspen and sustain fire spread in aspen fuels (Brown and Simmerman 1985). The only restriction required on fire intensity is to maintain control. Strip head fires will normally be necessary to obtain adequate spread of fire throughout the burn unit. Achieving sustained fire spread with sufficient intensity to meet objectives is often difficult in this situation because of light surface fuel quantities and high fuel moisture contents. Fuels adjacent to aspen stands are usually drier and more flammable. Sometimes this can be used to advantage by running fire into aspen stands with sufficient intensity to meet objectives. Aerial ignition may also be helpful in generating sufficient fire to kill aspen and small conifers.

Fall is the best time to burn, especially where consumption of forest floor duff is necessary to expose mineral soil. Moisture content in the lower half of the duff should average less than 100 percent to remove adequate duff. If exposure of mineral soil is not needed or of secondary importance, spring burning may be possible. Spring burns should be scheduled when fine dead fuels are dry enough to burn but before live vegetation greens up. However, this period is short, making it difficult to achieve success.

Prescription conditions are similar to those for other situations (table 1). The best time to burn, however, is in early fall after at least 50 percent of the herbaceous vegetation has cured and before rainfall has soaked the duff (Brown and Simmerman 1985). The chance of meeting all fire objectives is best at this time.

Fuels.—In open stands of aspen where shrubs, herbaceous vegetation, and downed woody fuels are adequate to sustain spread of fire with 2-foot or larger flames, fuel treatment is unnecessary. Where fuels are sparse, cutting of both aspen and conifers can improve effectiveness of the prescribed fire. Cutting adds surface fuels, which increases fire intensity. Both aspen and conifers should be cut at the same time to create fuel and help meet the objective of reducing conifers.

Sparse fuel, consisting primarily of live vegetation, presents the greatest difficulty to burning in the aspen situation. Aspen clones that are unlikely to support fire should be recognized (Brown and Simmerman 1985). If cutting is not an option to enhance flammability, effort to burn these clones is not worthwhile. Other opportunities should be sought.

SITUATION 6: Douglas-fir Sapling/Pole Stage in a Douglas-fir/Pinegrass h.t.

SITE CHARACTERISTICS

Density		
Trees[1]		Seedling and sapling[2]
(No./acre)	Basal area *(Ft²/acre)*	*(No./acre)*
440	54	120

Cover *(percent)*		
Conifers	Aspen	Shrubs
80	3	3

	Fuel loading *(lb/acre)*
Grass and litter	3,820
Live shrub	4,550
TOTAL	8,370
Downed dead woody 3+inches	31,030

Herb and shrub composition

Pinegrass, basin wildrye, Richardson needlegrass, Oregon-grape, violet, white spiraea, strawberry, western yarrow, aster, snowbrush ceanothus, mountain big sagebrush, rose, squaw currant

[1]Trees (conifers) over 10 feet high.
[2]Trees (conifers) less than 10 feet high.

VEGETATION CHARACTERISTICS

Situation 6 is illustrated here by a Douglas-fir/pinegrass habitat type occupied by sapling and pole-sized Douglas-fir. Other moist Douglas-fir habitat types are similar. They characteristically occur on north aspects, along riparian zones, and in moist swales. Because wildlife values are high, management of these situations is of major importance. Because of intermixing bunchgrass and pinegrass habitat types, treatment of one may facilitate treatment of the other. Douglas-fir/pinegrass habitat types have potential to support crown-sprouting shrubs. However, the understory on most sites is presently comprised of herbs such as pinegrass and heartleaf arnica.

Our example (fig. 7) is depictive of sites where deteriorated shrubs have been heavily browsed by wild ungulates because of limited availability. Squaw currant, snowbrush ceanothus, Scouler willow (fig. 8), aspen, rose, snowberry, white spiraea, and sagebrush are typically scattered through this vegetation type.

(A)

(B)

Figure 7.—Closeups of heavily browsed squaw currant (A) and snowbrush ceanothus (B). These shrubs appear at lower left (A) and upper right (B) of situation 6 photo.

Figure 8.—Remnant Scouler willow that is losing a battle for survival.

VEGETATION TREND

Historically, these sites supported open stands of Douglas-fir and patches of lodgepole pine. In our example, logging and slash burning occurred around 1900. This stimulated regeneration of aspen, willow, ceanothus, and other shrubs and herbs. However, the absence of disturbance for 80 years or more has resulted in displacement of forage plants by conifers. Many shrubs have died and surviving shrubs are largely confined to small openings. They are heavily browsed and low in vigor.

The continued absence of disturbance on situation 6 sites will further reduce the ability of shrubs to respond to fire. Eventually, survivor species (sprouters) will disappear, and plant response will depend upon seed from both onsite and offsite sources.

RESPONSE POTENTIAL

The potential of plants to respond to disturbance depends on their reproductive characteristics. Most species are capable of reproducing from basal buds. Some also regenerate from seeds stored in the soil (onsite colonizers) or from wind-blown seed (offsite colonizers) (Stickney 1982). Onsite colonizers commonly occurring in moist Douglas-fir habitat types include snowbrush ceanothus, elderberry, buffaloberry, squaw currant, and blackberry. Offsite colonizers such as aspen and especially willow and cottonwood also have a potential to regenerate from seeds carried in from adjacent areas. In general, the more severe the fire treatment, the more favorable the site becomes for establishment of

colonizers (Stickney 1982). Severe fires bare mineral soil essential for seedling establishment while activating onsite stored seed. Severe fires may kill some sprouters that arise from buds near the soil surface.

PRESCRIPTION CONSIDERATIONS

Resource Objective.—Increase coverage and productivity of shrubs. Increase diversity of plant species by recruitment of colonizer species.

Fire Objectives.—Kill shrubs above ground and expose 30 to 50 percent mineral soil. This will stimulate sprouting of existing shrubs and trees such as aspen. Create a favorable seedbed for establishment of colonizer species such as willow and cottonwood.

Kind of Fire.—A heading fire is the most practical. Wide strips should be ignited where the fuel continuity supports sustained fire spread. Otherwise narrow strips may be required to obtain the desired fire treatment. Flame lengths greater than 1 foot, which is near the lower limit for sustained fire spread, are suitable. Acceptable maximum flame lengths depend on requirements for control if the burn is in a clearcut. If the burn is beneath standing trees to be kept alive, flame lengths mostly less than 2 feet are desirable. Late summer or early fall is the best time to burn to expose 30 to 50 percent mineral soil. Moisture content of the lower half of the duff should average less than 100 percent to achieve adequate consumption of duff. A wide range in fine fuel moisture is acceptable if duff is adequately dry (table 1).

Fuels.—Some sites representing this situation will require addition of slash fuels to achieve effective spread of fire. Where this is the case, opportunities to harvest conifers should be sought. Other sites may contain adequate surface fuels to support fire without additional slash. However, opening up the canopy is desirable for shrub growth. The success of fire treatments is greatly improved by cutting.

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APPENDIX I: PLANTS DISCUSSED IN TEXT

Common name	Scientific name
Trees	
Douglas-fir	*Pseudotsuga menziesii*
ponderosa pine	*Pinus ponderosa*
limber pine	*Pinus flexilis*
lodgepole pine	*Pinus contorta*
Rocky Mountain juniper	*Juniperus scopulorum*
cottonwood	*Populus* spp.
aspen	*Populus tremuloides*
Shrubs and Subshrubs	
antelope bitterbrush	*Purshia tridentata*
curlleaf mountain-mahogany	*Cercocarpus ledifolius*
mountain big sagebrush	*Artemisia tridentata vaseyana*
three-tip sagebrush	*Artemisia tripartita*
silver sagebrush	*Artemisia cana*
fringed sagebrush	*Artemisia frigida*
rubber rabbitbrush	*Chrysothamnus nauseosus*
green rabbitbrush	*Chrysothamnus viscidiflorus*
squaw currant	*Ribes cereum*
white spiraea	*Spiraea betulifolia*
snowberry	*Symphoricarpos* spp.
kinnikinnick	*Arctostaphylos uva-ursi*
buffaloberry	*Shepherdia canadensis*
western serviceberry	*Amelanchier alnifolia*
elderberry	*Sambucus racemosa*
chokecherry	*Prunus virginiana*
snowbrush ceanothus	*Ceanothus velutinus*
Scouler willow	*Salix scoulerana*
rose	*Rosa* spp.
blackberry	*Rubus* spp.
Graminoids	
Idaho fescue	*Festuca idahoensis*
rough fescue	*Festuca scabrella*
bluebunch wheatgrass	*Agropyron spicatum*
slender wheatgrass	*Agropyron trachycaulum*
thickspike wheatgrass	*Agropyron dasystachyum*
needle-and-thread	*Stipa comata*
western needlegrass	*Stipa occidentalis*
Richardson needlegrass	*Stipa richardsoni*
junegrass	*Koeleria cristata*
carex	*Carex* spp.
pinegrass	*Calamagrostis rubescens*
oatgrass	*Danthonia intermedia*
basin wildrye	*Elymus cinereus*
mountain brome	*Bromus marginatus*
Forbs	
western yarrow	*Achillea millefolium*
puccoon	*Lithospermum ruderale*
heartleaf arnica	*Arnica cordifolia*
fernleaf fleabane	*Erigeron compositus*
aster	*Aster* spp.
Missouri goldenrod	*Solidago missouriensis*
prairiesmoke	*Geum triflorum*
strawberry	*Fragaria virginiana*
sulpur eriogonum	*Eriogonum umbellatum*
common dandelion	*Taraxacum officinale*
lupine	*Lupinis sericeus*
violet	*Viola* spp.
Oregon-grape	*Berberis repens*

APPENDIX II: FLAMMABILITY OF GRASS FUELS

Burning can be difficult if fuel quantities are insufficient to support sustained fire spread. The situations in figure 9 illustrate the influence of grazing on fuel quantities and flammability. Figure 9 can serve as a guide for planning adequate fuels to carry prescribed fires.

A. Grazed, 300 lb/acre. Grass alone will not support fire spread. Addition of sagebrush exceeding 20 percent cover can support fire spread with winds of 8 to 14 mi/h.

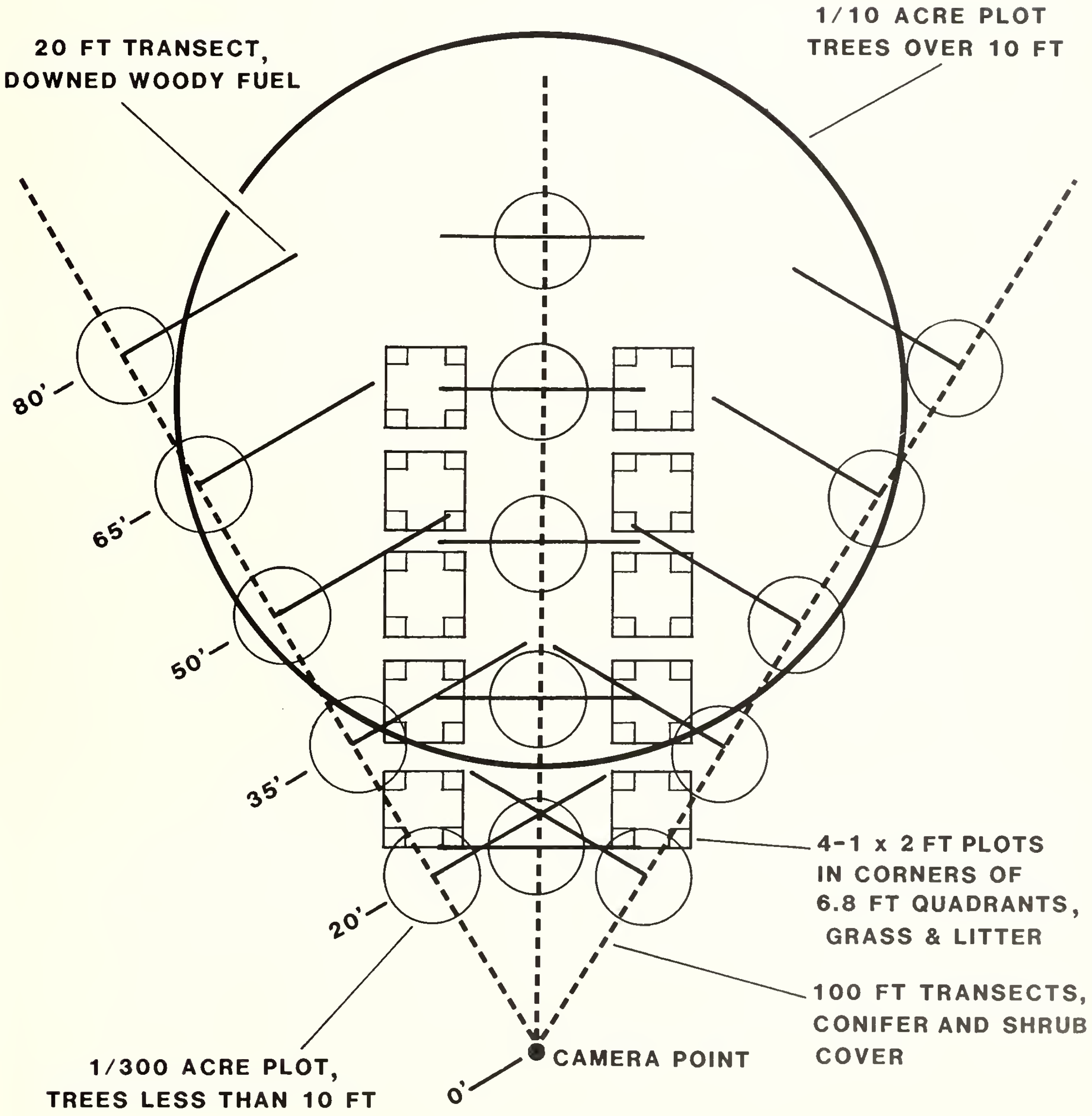
B. Grazed, 465 lb/acre. Grass alone will not support fire spread. Addition of sagebrush exceeding 15 percent cover can support fire spread with winds of 8 to 14 mi/h.

C. Light grazing, 765 lb/acre. Fire may spread in grass alone, but continuity of fuel is marginal. Addition of sagebrush exceeding 10 percent cover can support fire spread with winds of 8 to 14 mi/h.

D. Ungrazed, 1,200 lb/acre. Grass alone can support fire spread. Addition of sagebrush increases fire intensity.

Figure 9.—Fuel loadings of a mixture of junegrass, bluebunch wheatgrass, and rough fescue, and flammability based primarily on a hypothetical relationship by Britton and Ralphs (1979).

APPENDIX III: LAYOUT OF SAMPLING PROCEDURE USED TO MEASURE VEGETATION AND FUELS AT PHOTO PLOTS



Gruell, George E.; Brown, James K.; Bushey, Charles L.
Prescribed fire opportunities in grasslands invaded by Douglas-fir: state-of-the-art guidelines. General Technical Report INT-198. Ogden, UT: U.S. Department of Agriculture, Intermountain Research Station; 1986. 19 p.

Provides information on use of prescribed fire to enhance productivity of bunchgrass ranges that have been invaded by Douglas-fir. Six vegetative "situations" representative of treatment opportunities most commonly encountered in Montana are discussed. Included are fire prescription considerations and identification of the resource objective, fire objective, kind of fire needed, and fuels.

KEYWORDS: Douglas-fir, bunchgrass, mountain big sagebrush, prescribed fire, livestock, big game

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